Ontario

THE REPORT OF THE

Royal Commission on Electric Power Planning

Chairman: Arthur Porter

VOLUME 6

Environmental and Health Implications of Electric Energy in Ontario

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The Report of the Royal Commission on Electric Power Planning

List of Volumes

The Report of the Royal Commission on Electric Power Planning is comprised of the following volumes:

Volume 1: Concepts, Conclusions, and Recommendations

Volume 2: The Electric Power System in Ontario

Volume 3: Factors Affecting the Demand for Electricity in Ontario

Volume 4: Energy Supply and Technology for Ontario

Volume 5: Economic Considerations in the Planning of Electric Power in Ontario

Volume 6: Environmental and Health Implications of Electric Energy in Ontario

Volume 7: The Socio-Economic and Land-Use Impacts of Electric Power in Ontario

Volume 8: Decision-Making, Regulation, and Public Participation: A Framework for Electric Power Planning in Ontario for the 1980s

Volume 9: A Bibliography to the Report

VOLUME 6

Environmental and Health Implications of Electric Energy in Ontario

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Foreword

The Commission wishes to acknowledge the contributions to our Report made by the authors of this volume. The enormity of the task as well as the skill and tenacity with which it was performed are testimony to the talents of F. Christof Haussmann and J. Rennie Whitehead. Our work would have been immeasurably more difficult without their assistance.

This volume, *Environmental and Health Implications of Electric Energy in Ontario*, focuses on a key issue area raised by the public during the Commission's public hearings process. The analysis, conclusions, and recommendations reflect data received by the Commission in the form of public testimony and exhibits, consultants' reports, and independent research and analysis by the authors. We have relied heavily on this work in formulating our own conclusions and recommendations in Volume 1. However, the views expressed in this volume are ultimately the responsibility of the authors. This document is therefore best viewed as a background paper which attempts to draw together the detailed evidence and analysis available on this complex subject, in a fashion which will be of use to the general public as well as to the technical community.

The research and evolution of this document were directed and reviewed for the Commission by Philip A. Lapp and Peter G. Mueller.

Arthur Porter, Chairman.

Executive Summary

Concern over the environmental and health effects of modern energy-intensive industrial processes has been slow to develop. Since the Industrial Revolution began, the notion that environmental degradation is an inevitable cost of economic growth has predominated for all but the last quarter-century. The recent concern over environmental quality was amply demonstrated by submissions to the Commission, many of which focused on the dangers from poisonous substances and construction works to man's health and comfort, and indeed to the well-being and survival of plants, animals, and the many other components of the environment around us. Because we are dependent on the environment for all our basic needs, we must know how nature works in order to protect our health against dangerous effects of electric power projects. These effects range from matters of primarily local concern, such as heat discharge in cooling water and the dust and sediment created during construction, through to global concerns, such as the creation of acid rain, the rise in atmospheric carbon-dioxide levels, and the disposal of highly toxic, radioactive wastes that will be dangerous for thousands of years.

The major sources of electric power available to Ontario in the next 20 years are coal-fired and nuclear generation plants. Oil and natural gas fuelled only 4 per cent of the province's total electric generation in 1978, and this small percentage is expected to shrink still further in the future. By contrast, hydraulic generation represented 38 per cent, coal-fired generation 28 per cent, and nuclear generation 30 per cent of the 1978 total. Looking to the year 2000, this generation mix, as it is called, will change considerably. Depending upon a number of factors, hydraulic generation will decline to between 16 and 22 per cent, fossil-fuelled generation will constitute between 15 and 35 per cent, and nuclear generation will be between 46 and 69 per cent of total electric power production; virtually all the fossil-fuelled generation is coal-fired. So the planning of Ontario's generation programme is governed essentially by two considerations: the rate at which the demand is expected to grow and the relative importance assigned to coal-fired and nuclear generation. The environmental and health impacts derive from the various stages of the fuel cycles: extraction, refining, processing, transportation, generation, distribution, and waste disposal.

Environmental and health effects of uranium and fossil-fuel cycles are very different, and therefore difficult to compare. There is greater similarity between the two fuel cycles at the mining stage than at any other stage; in both cycles, the sheer volume of tailings and acid drainage from tailings present serious environmental problems. However, the effects of coal-mining occur entirely outside the province, whereas virtually all of the uranium used by Ontario Hydro is mined in Ontario. Furthermore, uranium-mining presents a major environmental concern in the long-lived radioactivity of tailings and the resulting dangers from radon gas and dissolved radium in nearby water systems; permanent containment of uranium tailings has not yet been achieved, and further development of disposal methods is required.

The great distances and volumes involved in transporting coal to Ontario's generating plants result in the allocation of significant areas of land to railway tracks, in coal dust being distributed throughout the atmosphere, and in deaths and injuries from accidents. By comparison, the transportation of fuel for Ontario's nuclear reactors is essentially free of any such impacts because of the small bulk and short distances involved.

Aside from thermal releases and transmission-related effects, neither of which are considered major threats to the environment, the environmental and health effects of coal-fired and nuclear generation are almost totally different in nature. The major issues related to coal-fired generation concern the amount of nitrogen and sulphur emitted and the distribution and control of the resulting oxides of sulphur and nitrogen, which combine with water in the atmosphere to produce acid rain. Also, as with all fossil fuels, the burning of coal contributes significantly to the build-up of carbon dioxide in the earth's atmosphere. Estimates of health impacts directly or indirectly attributable to releases of sulphur dioxide to the atmosphere are highly controversial because of the difficulty of separating these effects from effects due to other factors, but they are thought to be considerable. The technology for controlling sulphur dioxide emissions from coal-fired generating stations is available, but expensive; the capital cost of equipping existing Ontario stations is estimated at more than $1 billion, and the operating cost at the equivalent of a $10-a-month increase in the average consumer's electricity bill. These effects all result from the normal operation of coal-fired generating stations.

The major risks associated with nuclear generation result from potential abnormal operation due to

component failure, faulty operation, accident, or sabotage. During normal operation, nuclear generating stations present very low levels of risk to workers, the public, and the environment. The most significant environmental impact of nuclear generation under normal operating conditions is the release of tritium via the once-through cooling system. Tritium levels in Lake Ontario could increase fivefold by the year 2000, raising the average per capita radiation intake from drinking water to 0.3 millirem per year. This impact is unique to the CANDU reactor because it uses a heavy-water moderator. Similarly, impacts associated with heavy-water production are unique to the CANDU system. The major concern here is with the potential for accidental releases of large quantities of hydrogen sulphide, a highly toxic gas.

With respect to post-generation waste disposal, the nuclear fuel cycle presents far greater problems than the coal fuel cycle. The major difficulty in the coal fuel cycle at this stage results from the need for quite large landfill sites for ash disposal, in the vicinity of the generating stations. Furthermore, care must be exercised to prevent contamination of water supplies by acidic leachates. But the technology to deal with these problems is well known, if not infallible, and has been in use for many years. By comparison, techniques for the disposal of radioactive wastes (including spent fuel disposal) are still in the developmental and experimental stages. The main problem is that these wastes must be protected for many centuries from great heat, seismic disturbance, and the movement of ground water. A further complication arises from the need to isolate the low-level radioactive wastes, for considerable periods of time. These wastes include virtually the entire shell of the nuclear generating station. The mechanism apparently most feasible for dealing with this problem is the "burial" of the plant on its own site, which requires sites to be properly selected at the outset to ensure that this option is not foreclosed.

The principal environmental impacts of the coal fuel cycle, then, are: atmospheric pollution from sulphur dioxide, nitrogen oxides, and carbon dioxide emissions; land taken up by coal storage, transportation, and waste disposal facilities; and potential water contamination by acidic leachate from ash-disposal sites. The hazards from the nuclear fuel cycle that are of greatest concern are contamination of water bodies by radioactive and acidic leaching from mill tailings, emissions of radioactive gases due to abnormal reactor operation, and the long-term effects of waste disposal and decommissioning.

There are some significant environmental impacts associated with hydroelectric power generation, including dam construction, the displacement of people, flora, and fauna from reservoir basins, and the transformation of river characteristics. However, few sites with substantial hydroelectric potential remain in the province, and this source will play only a relatively small role in the expansion of Ontario's generation system. Alternative renewable energy sources, such as solar photovoltaic, solar thermal, and wind d generation, have a potentially more important future, but only well beyond the year 2000. Impacts from these technologies that are identifiable at present occur mainly in the manufacture of materials and the construction of facilities. One advantage of these sources is their natural distribution system. From the point of view of minimizing health and environmental impacts, it would be prudent to take advantage of this free distribution, thereby adding to the security of local supply while avoiding distribution-related impacts and inefficiencies.

Several conclusions may be drawn, concerning the impact of electric power generation, in the light of the hypothesized alternative courses of development for Ontario's generation expansion programme. At a low (2.5 per cent) average per annum growth rate of demand for electric power, the already committed programme of nuclear expansion, which includes construction of the Darlington Generating Station, is more than sufficient to meet requirements to and beyond the year 2000. In this scenario, the sources of generation are distributed as follows: hydraulic – 22 per cent, nuclear – 57 per cent, and coal – 21 per cent. The total amount of electric energy generated in the year 2000 would be 68 per cent greater than in 1979. Only small increases over present land requirements would be experienced as a result of an increase in mill tailings. Depending upon developments in the technology for disposing of high- and low-level radioactive wastes, however, land requirements may be substantial, especially if "burial" is adopted as the way to dispose of decommissioned nuclear stations. Major radiation releases to water will double, and, although radioactive releases to the atmosphere would also double, the latter are thought not to present any significant risks under normal operating conditions.

At medium (3.5 per cent) and high (4.5 per cent) growth rates of demand for electric power, generation expansion beyond the committed programme would be required before 2000. The options being considered are continuation along the "nuclear path" and redirection to a coal-fired programme, whereby two additional coal-fired stations would be built for each new nuclear station constructed. For convenience,

these are called the "high-nuclear" and "high-coal" options, respectively. Alternative sources of electric power may begin to appear even before 2000, but for several decades to come the overriding environmental and health effects will result from these traditional generation technologies.

At the 3.5 per cent growth rate, electricity requirements in 2000 would be 106 per cent above 1979 levels. By the year 2000, total annual land requirements for mill tailings and ash disposal would increase by 40 per cent in the high-nuclear option and by 100 per cent in the high-coal option. Again, land requirements for nuclear waste disposal are not included in these figures. Annual radiation releases to water would more than double in both the high-coal and the high-nuclear options, and acid drainage from coal piles and ash disposal would increase by 30 per cent in the high-nuclear option, and by 100 per cent over 1979 levels in the high-coal option. Similarly, airborne contaminant releases from coal-fired generation would increase by 30 per cent over 1979 annual levels for the high-nuclear option and by 100 per cent for the high-coal option, assuming the existing level of environmental controls. Also, the risk of accidental releases from nuclear generating stations will increase proportionately with the number of operating reactors (see Table S.1).

Table S.1 Operating Nuclear Reactors for 1979 and 2000: Scenarios

Average annual growth rate, 1979 to 2000	Scenario type	Number of operating reactors
zero (1979 level)		8
2.5 per cent	high-nuclear	21
3.5 per cent	high-nuclear	25
3.5 per cent	high-coal	21
4.5 per cent	high-nuclear	35
4.5 per cent	high-coal	25

At the 4.5 per cent growth rate, impacts on land, water, and the atmosphere increase rapidly. In particular, impacts on water become very high for both the high-nuclear and the high-coal generation expansion options, and atmospheric impacts are severe in the high-coal option.

One observation of particular significance concerns the sensitivity of environmental impacts to load growth and generation mix. It is clear that, while variations in generation mix influence the nature of the environmental impacts considerably, they leave the decision-maker with the need to make trade-offs among different impacts. There are no definitive criteria which assist in making these trade-offs as long as regulatory standards are met. Is a fourfold increase in radiation release to water preferable to a threefold increase in acid drainage? Environmentl impacts are also seen to be highly sensitive to the growth in demand for electric power. Here, the effect is more straightforward: less growth equals less impact. Reductions in impact for any single environmental factor can usually be achieved more readily by reducing the average annual growth rate than by adjusting the generation mix. This observation leads to the conclusion that conservation is the best strategy for minimizing environmental and health impacts, at least in the medium term until more benign technologies become available.

The unknown in the above discussion of environmental impacts is the effects of accidental releases of radiation from nuclear plants. It is virtually impossible to quantify these potential effects, as they depend on a great variety of local topographical and meteorological factors. These effects are usually taken into consideration only insofar as they are included in probability estimates of health effects. Estimates of health impacts associated with each stage of the coal and nuclear fuel cycles are available, primarily from U.S. literature. These estimates are highly controversial and do not take into account differences between the U.S. and Canadian technologies. When these estimates are applied to the scenarios under consideration for Ontario's electric power generation programme to the year 2000, the high-nuclear scenarios invariably look superior to the high-coal scenarios (see Table 8.6). These figures must be interpreted very cautiously, however. It must be remembered that health effects associated with the production of heavy water and the release of tritium in cooling water are not included. It must also be remembered that technological means to reduce atmospheric emissions from coal-fired generation are readily available, though at considerable cost. And, finally, the great uncertainty associated with these estimates must not be forgotten.

The questions decision-makers must consider in evaluating environmental and health risks include:

- Distribution – Is the risk local, regional, or global, and is it borne primarily by those who benefit from the project or are the benefits and risks inequitably distributed? Furthermore, do those who

live with risk do so knowingly and voluntarily, or do they have little or no choice in the matter, perhaps out of ignorance?

- Frequency – Are the consequences of the risk likely to occur frequently, occasionally, or almost never? What is the probability that the consequences of the risk will occur in any given year?
- Consequences – Are the potential effects of the action or risk severe, moderate, or negligible? The evaluation of consequences must include consideration of the degree of reversibility of any given consequence. The lower the degree of reversibility, the more severe the consequence.

These dimensions are not always considered by the public in passing judgement on alternative technologies, and there is a great need for public education on the nature of the risks in all these matters.

Public education and the regulation of the environmental and health impacts of energy technologies are the two most effective risk-management tools. Some key points from the above review of regulations governing energy technologies may be summarized as follows:

- The recent international concern over acid rain strongly suggests that emission controls in Ontario will have to match controls in the U.S.
- Legislative provisions for the enforcement of international agreements on air quality control are now in place at the federal level.
- The greatest uncertainty over regulatory responsibility and authority exists at the mining stage of the fuel cycles.
- Additional contaminants must be regulated, and responsibility for monitoring must be clearly allocated.
- Provincial authorities should strengthen their regulation of the occupational environment in mines, and federal authorities should concentrate on researching and recommending minimum national standards.
- The major regulatory shortcoming is the complete lack of standards or other requirements governing the post-closure phase of nuclear facilities, including tailings disposal areas. Efforts are under way at both the federal and the provincial level to redress this gap, which is an issue of the greatest urgency.

Above all, this review leads to the conclusion that a great deal more work needs to be done before answers to many of the questions, some of them unique to Canada, will be found.

CHAPTER ONE

Major Environmental Concerns

To introduce the subject of the environment, we cannot do better than quote from a statement by the science advisor to the Department of the Environment, E.F. Roots:

> The environment provides all our tangible assets. It includes everything we have or can ever have in terms of physical or biological resources; it is the support of life and it provides the total basis for our activities, now and in the future. . . . The history of various civilizations has been one of learing to use environmental resources to provide an excess over immediate biological needs and thus to accumulate material gains, or time, or energy, for purposes other than biological survival. How well we in Canada use our ingenuity and institutions to turn our environmental assets into wealth, the use of other resources or the satisfaction of future needs, depends to a large extent on how well our institutions and our decisions operate within the physical and biological realities of our environment. Our prosperity, our wealth, our health and our culture are related to how well we consciously or unconsciously understand the Canadian and world environment. . . . Perhaps to a greater extent than the people of most countries, Canadians are directly affected in their daily lives by the natural environment. We are the residents of a large country, most of it of such low biological productivity and of such harsh climate that nine-tenths of us live in a narrow strip along the southern border. We are highly urbanized, more so than many more populous countries, but our cities are widely separated, so that year-round interurban transport and communications are very important to our social and commercial life. However, the environmental conditions are such that year-round maintenance of this transport and communications network poses problems and expenses faced by few other nations. We have a growing season that is very short except in one tiny portion of the country; most of the land is dormant for six months of the year, and humans and wildlife alike must live on stored food and energy for half the year – or else migrate to warmer regions. Our country is characterized by great geographical and environmental diversity – plain and mountain, rainforest and semi-arid grasslands, fertile soil and barren rock, marine and continental climate; and yet we have developed and endeavoured to maintain a relatively uniform material standard of living and life style that in many ways reflects more the aspirations and adaptations to their local environment of those who live in the United States or Western Europe, than it does a deliberate adaptation to the Canadian environment. We pay for it in heating bills – we have the largest amount of heated indoor space per capita of any country – in transportation costs, in salt-corroded cars, in income supplements to fishermen, in fluctuating food costs. We also enjoy our environment. It gives us our relative abundance of food, our surplus grain which we can share with the world. It gives us our forests, our abundance of fresh water, our colours in the autumn and our flying geese in the spring. Although most of us live in cities, we tend to think of Canada as a country with wild land and open spaces; a large number of us identify with the "natural" environment and feel it gives us a distinctive national character. At least half of us maintain or use, by choice, a second dwelling or camp in the country during our leisure. Our direct participation in sporting activities that put us in direct contact with the natural environment – fishing, swimming, canoeing, skiing – is far greater than our public participation in sports where we compete against one another. By coping with environmental obstacles, and identifying and enjoying the environment as a part of our life, we give the environment a value which is subjective as well as intrinsic.[1]

This eloquent statement encapsulates views that the RCEPP heard from many Ontarians who chose to testify. Does this mean that concern for the environment must play a large part in the future of the province's power development? What specific impact will such development have on things that the people cherish?

Concern for the Environment

Public interest in the issues named by Roots began to gather momentum in the 18th and 19th centuries, as the problems of public health compelled cities to look for pure water supplies, and for better ways of disposing of refuse and ordure. The Industrial Revolution strengthened this concern. Huge populations grew up in urban areas that could not house them properly, nor dispose of the wastes that they generated. Toxic gases from chimneys, and liquids from exhaust pipes, devastated the streams and landscapes of the industrialized areas. Britain, the Low Countries, and Germany, in particular, suffered untold damage to health, amenity, and nature. More than any other single factor, it was the burning of high-sulphur coal for power and in the iron and steel industry that led to the damage.

The politics of the time forbade any real attempt to stop the rot. Public-health reformers succeeded in

forcing better standards of drinking water and sewage on reluctant governments. But little could be done to protect nature. The legacy is visible even today in the industrialized areas of Europe. North America suffered less, but was still damaged. *Laissez-faire* economics argued that such effects were the inevitable costs of economic growth. They were balanced by gains in material welfare, even if the latter was unevenly distributed.

Our own times have seen a reversal of this cynical fallacy. The 1960s and 1970s have been decades of environmental action. Public awareness of threats to health and to nature has grown rapidly. At first, the concern was for environmental damage, industrial pollution, and threats to public health. Quickly, however, it spread to include protection of plants and animals. "Ecology" became and has remained a household word. Governments have set up elaborate means of protecting the environment against industrial development. We now take it for granted that protection of the environment and of public health are essential parts of good government. Much of the evidence heard by the RCEPP has attested to this fact.

Our concern still has two main facets:

- We fear that poisonous substances released by industry may affect our health and comfort. These substances reach us through the environment. They are airborne or waterborne, and they are diffused widely over areas that may be a great distance from the polluter.
- We also feel a concern for wild things around us, and especially for plants and animals (including fish) that may be affected by pollution, or by construction work. In part, this springs from anxiety for our own well-being. Nature is, after all, the resource that sustains us. But many people feel the need to protect nature for its own sake. Thoreau said, "In wildness is the preservation of the world." More and more people agree with him.

There is no sign that public concern is dying down. As each issue becomes prominent, there is an outcry and the media give it much attention. Measures are taken to tackle the problem and the concern dies down. Each issue has a short history, with a peak lasting only some months, or a year or two. But other issues take its place. The general sensitivity to environmental matters does not fluctuate much. Public spokesmen often assert that the environmental movement is dead – only to be proved wrong by another uproar over some new proposed energy development.

A key issue faced by the people of Ontario is that electric power development seriously affects the environment. Coal-fired generating stations release sulphur and toxic wastes from their smokestacks. Nuclear stations emit small, controlled amounts of radioactive gases and liquids, and produce some large quantities of very toxic wastes within the stations themselves. Both types of stations release waste heat into rivers and lakes. Hydroelectric plants drown large areas of land, and their plants and animal habitats. Transmission lines, pipelines, and the road, rail, and shipping routes needed to service industry complete the impact. Electric power generation is responsible for a significant part of the impact of man on his environment.

If, therefore, we seek to raise our living standards by a further expansion of electric power generation, regardless of the type, we must face the facts:

- For every benefit we gain, there must be an environmental cost, which we must try to minimize, and then weigh against the value of the benefit.
- Both benefits and costs are unequally distributed among Ontario's regions, and therefore among its people.
- Ontario is part of the larger Canadian community and, beyond that, of the world community, and the environmental costs of power development rarely stop at provincial or national boundaries.
- The answers can rarely be based on hard dollar figures. Often they will depend on ethics – on value judgements that resist all attempts to put numbers against either the costs or the benefits.

Can We Separate Health and Environmental Effects?

Experience soon shows the impossibility of separating health effects from impacts on the natural environment. In practice, our society has seen these as separate concerns. We have set up institutions to deal with each of these concerns as if they represented different problems. Such a separation makes little sense when we consider the impact of energy projects. As we shall see repeatedly, the hazards to health reach the individual citizen by environmental pathways. We cannot protect ourselves without protecting the environment as well.

Human health may be affected by substances that we inhale (particles or gases) or simply swallow

(contaminants in food and drink). In a few cases these substances may enter the body through the skin. We may also be affected by different kinds of radiation, and by the temperature of the air surrounding us.

Only a small part of the population is close enough to power generating stations or transmission facilities to experience such effects directly. This is the labour force that mines the coal or the uranium and tends the power stations and transmission lines. Many types of power-related industries do indeed create serious occupational health hazards, in which the worker has no choice but to expose himself to health risks while doing his job. The exposure of uranium-mining and -milling operators to radioactive radon gas is an example of such direct danger. Society has a duty to require that the industry take all possible measures to minimize the health hazard to the worker, and to ensure that workers are clearly aware of the short- and long-term risks to which they will be exposed in the course of their employment.

Most of us, however, live well outside the mine entrance, the generating station fence, or the direct path of an electricity transmission line. For the majority, there will be a health hazard only if there is an environmental route – called a pathway – that leads from the source to the main mass of the population.

Thus, for example, the radioactive tritium released in small quantities from nuclear generating stations can reach us in one of three ways. It may enter our lungs as part of the water vapour that all air contains. Wind systems and their associated eddies may carry it towards us. Or we may drink it as part of our water supply, which may be piped in from Lake Huron or Lake Ontario; it is constantly being released into the lakes by the cooling systems of generating stations. Or we may eat vegetables, cereals, or meat that have picked up the toxins from rain. In each case there is a recognizable environmental pathway whereby the contaminant can reach us (see Figures 6.1 and 6.2 of the RCEPP *Interim Report on Nuclear Power in Ontario*).

To protect human health against the dangerous by-products of the energy industry we must know how the natural environment works – how winds, lakes, and streams behave, how plants build their tissues, and how contaminants accumulate in the organs of plants and animals. And we must be able to predict and monitor changes in the way the environment will react if we alter it deliberately or inadvertently. Health protection demands that we understand how the environment works *as a system*. We must understand the ecosystem.

The Question of Culprits

Public regulation of the environment and of factors affecting our health has generally assumed that most of us are innocent and that only a few are guilty. It appears easy to control air pollution, for example, if we attribute it to black smoke coming from a single chimney. It is easy to blame large, identifiable corporations for damage to the environment. It is much harder to act when there are many culprits. It may be literally impossible if all of us are in some way guilty.

Many of the health hazards and environmental stresses created by the energy industry present this difficulty. In the following paragraphs, three issues of this kind will be analysed. In one of them, the buildup of carbon dioxide in the atmosphere, we are all to blame. No living being can escape the effect of nature's carbon cycle. All of us use some form of carbon-rich fuel. At the opposite extreme is nuclear power, where the culprits are very few in number, and all highly visible. Somewhere between these extremes lies the problem of acid rain. There are some giant corporate culprits that contribute the sulphur that is mainly responsible – but there are also innumerable tiny sources that cannot be so easily identified.

One cannot establish sensible public policy in this area unless this is faced. Whether or not one can protect the public against health hazards, or the environment against stress, depends on the question of what to regulate – and how. Some matters may be beyond regulation. For example, an increase in energy consumption must inevitably lead to increased health and environmental impacts. Carbon dioxide release is in this category.

Three Issues and Their Resolution

The largest single issue created by our use of energy is the rising carbon dioxide concentration in the atmosphere. In Figure 1.1 we show an estimate of the concentration since 1860, compiled by W.W. Kellogg. Figure 1.2 shows actual measurements made in various places around the world, and a very detailed record from Mauna Loa, in Hawaii. The buildup is clear. In the 19th century, the concentration

Fig. 1.1: p. 7
Fig. 1.2: p. 8

of carbon dioxide was between 280 and 290 parts per million (ppm). Since then it has risen to about 335 ppm, and it is still rising at about 1 ppm each year. This amounts to 3 per cent per decade.

One may legitimately ask these questions:

- Does the increase matter?
- What causes it?
- What can we do about it, if it does matter?

The increase certainly matters, even though carbon dioxide is not harmful to man in such low concentrations. Present rates of increase will double the concentration by the middle of the 21st century. This doubling is likely to raise world air temperatures at the surface by two or three degrees Celsius, and more at the poles. This is likely to have grave effects on rainfall (and hence on world food production), largely because of a shrinking in the pack ice in the polar oceans. Details of the effect are at present unpredictable. Some regions will gain. Others will lose. It is quite impossible to forecast the effect in Ontario. We can hardly expect, however, to escape the sweeping changes that seem likely.

The increase in carbon dioxide is believed to be mainly due to the world-wide burning of fossil fuels and the loss of organic materials from ploughed or overgrazed soils. In round figures the world burns annually about 5 billion tonnes of carbon in the form of oil, coal, and natural gas. Two or 3 billion tonnes stay in the atmosphere and threaten to change world climate. The rest dissolves in the ocean, or is reabsorbed in plant growth. A shift from oil to coal or natural gas by the world's power industry will have little effect because all of these fuels release carbon. Of the available resources, only hydroelectricity, solar energy, and nuclear power release no carbon.

Can we do anything about it? Probably not, because there is no single culprit, no identifiable polluter. All of us use coal, gas, oil, or wood as fuel. Nearly all of us eat food derived from the use of soils whose carbon content is slowly being released to the atmosphere. No technology is available, at a reasonable price, to avoid the release of carbon from chimneys, exhaust pipes, campfires, and ploughed fields. Even the burning of cow dung by the Indian peasant contributes its share. And so we arrive at a major conclusion, which is that public policy cannot prevent the buildup of carbon dioxide in the atmosphere, however threatening the climatic changes that will ensue. What governments *can* do is to insist that the buildup be monitored, that all possible measures be taken to reduce it, and that the scientific community attempt to predict the environmental and socio-economic consequences. Only with such predictions can we hope to adapt successfully to the environmental changes and economic difficulties that will follow.

For Ontario, this is an issue in which our obvious course is to insist that Canada participate in international efforts to come to grips with the problems. These are now being discussed. The carbon dioxide effect will, for example, be at the heart of the World Climate Programme now being organized by various agencies of the United Nations, with the help of the International Council of Scientific Unions. When the outcome becomes clearer, political action will probably be taken internationally to help mitigate the effects, notably with regard to food supplies.

The acid rain effect has been widely publicized. It is often said that many Ontario lakes are now "dead" because the water flowing into them has become steadily more acidic. What this means is that the ecosystems within the lake have become unable to support the higher forms of life in which we are interested, notably sports fish.

This impact is real, though it is often oversimplified and exaggerated. The acidification of lakes, soils, and vegetation is a matter for serious concern in southern and eastern Ontario, as it is in much of the northeastern United States, southern Quebec, and the maritime provinces. Only where the bedrock and soils are naturally alkaline – as in the limestone areas around Kingston and Perth – may the rising acidity of rainfall actually be helpful to crops and forests. Elsewhere it is a clear threat to the biological productivity on which agriculture, forests, and fisheries depend.

The acidity of the rain falling on Ontario is typically 10 to 100 times higher than over western Canada and other thinly settled areas. The acidity probably arises from the incorporation into the rain of tiny sulphate particles, which are very abundant in the eastern part of North America. These particles in turn arise from the transformation of the gas, sulphur dioxide, which is emitted when sulphur-rich coal, oil, or lignite are burned, or when sulphide ores are smelted (as at Sudbury). The details of the chemistry are not yet completely understood, but the two main areas of the world with very acid rainfall – northeastern North America and northwestern Europe – are both heavily industrialized areas where much coal and oil is burned.

Here again, the question of who is the culprit arises. Who are the polluters? It is very easy to point to the nickel producers of the Sudbury area, who together form perhaps the largest single producers of sulphur dioxide pollution in the hemisphere. The effects downwind from Sudbury on the vegetation, soil, and lakes are well known. It should be noted that this is not a power-related effect. The Sudbury chimneys serve metal production, not energy production. The reality is that most of the sulphur dioxide present in the fast-moving airstreams of North America comes out of furnace chimneys, from oil or coal fires, and from other exhausts. The culprits number not one million but tens of millions. Every house that burns oil in the furnace, every thermal power station that lacks expensive scrubbing equipment, is an emitter. In effect, we are nearly all culprits.

Moreover, the ebb and flow of winds across borders is such that much of the acidity of Ontario's rainfall comes from sulphur burned in the United States, and much of Quebec's problem comes from Ontario exhausts. A single large source at Atikokan will, from time to time, affect whole sections of the U.S.-Canadian border region. We do not have enough observations to prove this on a daily basis, but model calculations, plus expert experience, show that these trans-boundary flows are inevitable.

The acid rain problem thus cries out for intergovernmental and international agreement on suitable action. In the sections that follow, the scale of sulphur emissions resulting from both coal and oil consumption will be analysed, as will the technology available to minimize their impact.

A third major environmental issue raised by energy development is that of the safe disposal of wastes other than those deliberately released to the atmosphere. Hydroelectricity, solar energy, and natural gas produce little such waste. All three produce waste heat, and gas yields waste vapour and carbon dioxide, which are deliberately released into the environment. Coal produces large volumes of ash, some of which escapes as particles unless it is precipitated at the source. But the waste problem that has really caught public attention is that of the nuclear industry.

These wastes are solid, liquid, and gaseous, and many are highly radioactive. They pose so great a potential threat to workers in the plants and to anyone exposed to them that they must be rigorously isolated from human contact for immensely long periods. Nuclear waste management has become a highly developed technology, with an excellent safety record. In spite of this, there appears to be more public anxiety about nuclear wastes than about any other aspect of the energy-environment relationship.

Without doubt, this arises from the potential threat to human health. In the case of carbon dioxide buildup, the concern is with the gradual and unavoidable change in world climate, and with the consequent dislocation of the world food system. With sulphur dioxide and acid rain, the perceived threat is to the biological productivity of soils and water-bodies; there is a less direct threat to human health. Nuclear wastes, by contrast, produce ionizing radiation that is capable of killing humans directly, if the exposure level is great enough. If the victim lives, or if the dose is smaller, then he or she still has an enhanced probability of contracting cancer many years later. Cancer is a charged word in our society So the nuclear-waste issue has very high visibility, whatever its relative demerits may turn out to be in the long run.

More than in any other energy-related area, the nuclear-waste issue demonstrates the need to combine health protection and medical research with the knowledge of environmental scientists – especially freshwater ecologists, hydrologists, and ground-water geologists. For 25 years AECL has followed such a course, recognizing that only through an understanding of natural and man-influenced ecosystems can the pathways whereby contaminants can reach persons be predicted.

The nuclear issue differs in another clear-cut way. The potential culprits are only too visible - at Pickering, Port Hope, Bruce, or Rolphton – since they must belong to one of three public corporations – Ontario Hydro, Atomic Energy of Canada Ltd., and Eldorado Nuclear Ltd. Hence, public anxiety and political response can be sharply focused.

It follows, then, that in this case we can do something about the problem. The scientific and technical knowledge required is available. So are the necessary institutions. Even in this clear-cut case, however. the decisions as to the measures to be taken to protect the public and nature will have to be based on political argument and not on scientific evidence alone. Scientific study of the nature of the wastes, and of the environmental pathways whereby these might reach people, can give us an account of the level of risk involved – and technology can tell us how to minimize these risks. Whether the risks are acceptable or not, given the benefits conferred on society by nuclear power, is a question that cannot be answered scientifically. The choice must ultimately be made by the public and their elected representatives.

It is against this background that we must examine the complex question of the contribution of electric-power plants in Ontario to the general level of air, water, and radiation pollution and the consequent hazards to health and the environment. We shall first look at the proportions of total energy that are generated from coal, oil, gas, nuclear, and hydraulic sources. Then the characteristics of each technology will be examined from the point of view of the environmental and health hazards they potentially cause.

The Pattern of Electric Power Generation in Ontario

Practically all the electric energy that is currently being generated in Ontario is from hydraulic, coal, and nuclear power stations. In 1978 (the most recent year for which complete statistics are available) only 4 per cent was generated by other means. Table 1.1 shows the amount of energy that was generated by the various means, the percentage of installed capacity that was used, and the absolute amounts of fuel that were consumed. It shows that 37.4 per cent of the total energy was generated by hydroelectric stations, 30.3 per cent by nuclear stations, and 28.3 per cent by coal-fired stations. Only 2.2 per cent was generated from natural gas and 1.8 per cent from oil.

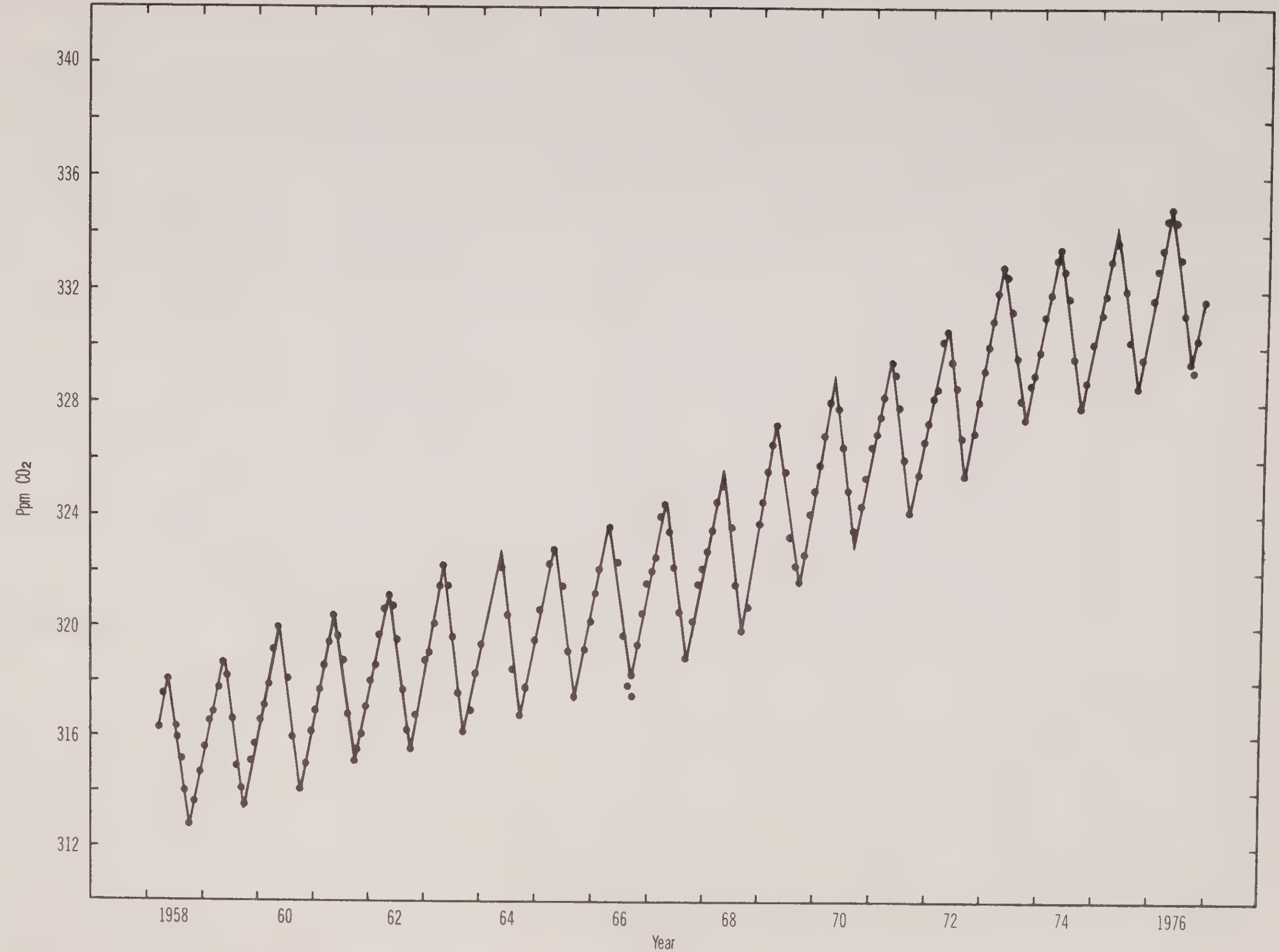
Table 1.1 Electrical Energy Generated in Ontario: 1978

Type of station	Generated energy			Percentage of total	Installed capacity	Percentage used	Amount of fuel used
	TJ	GW·h	GW·years				
Hydro	129,000	35,834	4.091	37.4	6.380	64.1	–
Coal	97,500	27,037	3.091	28.3	8.940	34.6	9×10^6 tonnes
Oil	6,300	1,739	0.199	1.8	2.222	9.0	2.5×10^6 bbl (3.42×10^5 tonnes)
Natural gas	7,500	2,079	0.237	2.2	0.600	39.5	$7.1 \times 10^8 m^3$
Nuclear	104,300	28,966	3.307	30.3	4.290	77.0	600 tonnes
Total	344,600	95,691	10.924	100	22.432	48.6	

Source: RCEPP.

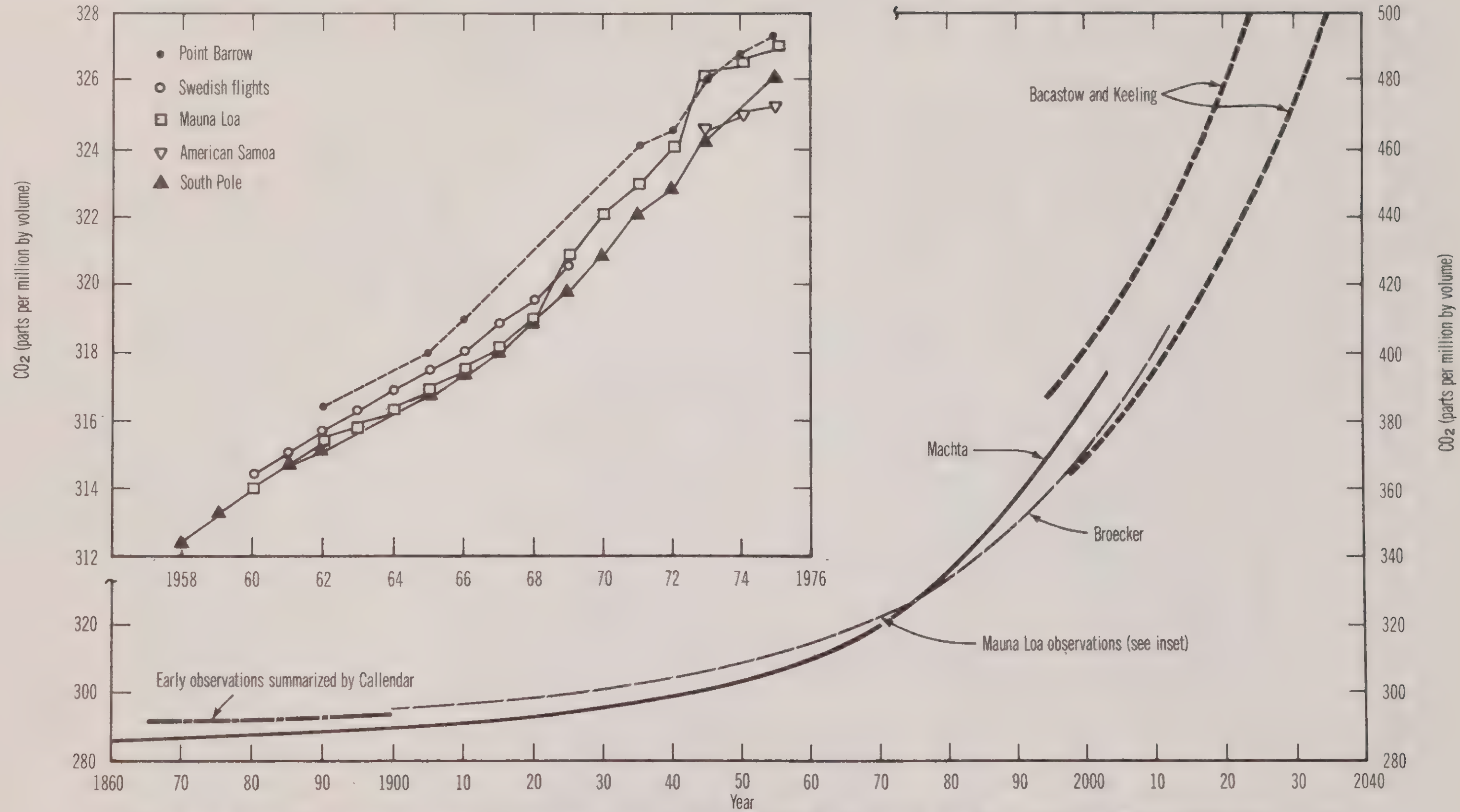
This pattern will not change quickly. The slow growth of energy consumption that is both encouraged and anticipated, together with the vested interest in present installed capacity, limits the rate of change. The use of oil is not likely to increase appreciably, in view of the expected world-wide shortage. Hydroelectric power is reaching its asymptotic limit and does not present the same kind of threat to human health and the environment that coal and nuclear power do. While the environmental and health effects of all current and potential methods for the generation of electric energy are treated below, it is recognized that coal-fired and nuclear generation have the greatest impact at present and will continue to do so for many years. Consequently, the following sections concentrate heavily on those two sources.

Figure 1.1 Mean Monthly Atmospheric Carbon Dioxide Concentrations at Mauna Loa, Hawaii (19°N, 3400 m Altitude)



Source: "Impact of Human Activities on Climate", by W. Kellogg, "WMO Bulletin": 1977, vol. XXVI, pp. 285-98; 1978, vol. XXVII, pp. 3-12.

Figure 1.2 Carbon Dioxide Concentration from 1860 to 1975 (Measured at Several Locations) and Some Estimates of Future Trends



Note: The early data were critically reviewed by Callendar (1958) and subsequently re-evaluated by Barrett (1975). The current series of observations for Mauna Loa are those reported by Keeling et al. (1976a) and C. D. Keeling (personal communication), for South Pole by Keeling et al. (1976b) and Keeling (personal communication), for American Samoa and Point Barrow by NOAA (1975) and T. Harris (personal communication), and for the Swedish aircraft observations by Bolin and Bischof (1970). Note that the carbon dioxide concentrations are given in terms of the "adjusted index values" (for the sake of continuity with the earlier data); it may be necessary to adjust these values upward by about 3 to 4 ppmv, according to Keeling et al. (1976a), to obtain the correct mole-fraction, but this would not affect the slopes of the curves. The model calculations predicting future carbon dioxide increases, by Machta (1973), Broecker (1975), and Bacastow and Keeling (1973), all take account of the take-up of anthropogenic carbon dioxide by oceans and the biomass (but in somewhat different ways), and assume a quasi-exponential increase in the rate of burning of fossil fuels (notably coal) in the next half-century or more. It is expected that in this time period about half of the new carbon dioxide released will remain in the atmosphere; and due to the slow mixing of deep ocean waters with the upper layers, the decay time of the added carbon dioxide, were we to stop producing it, is estimated to be 1,000 to 1,500 years.

Source: "Human Activities that Affect the Climate", by R. E. Munn and L. Machta, "Proceedings of the World Climate Conference," World Meteorological Organization, Geneva, 1979, pp. 170-209.

CHAPTER TWO

The Environmental and Health Impact of Coal-Fired Generation

The use of coal for the generation of electric energy has a deleterious effect on the environment and presents a hazard to the health and safety of workers in several occupations as well as to the health of the general public.

The impact on the environment and on human health comes not only from the burning of coal but from the mining, processing, and transportation of coal and the storage and disposal of waste after the coal has been burned. Even the construction and eventual decommissioning of power stations have some impact, particularly if the hazards associated with providing the energy, materials, and transportation involved in those activities are taken into account.

The nature of the environmental impact and of the short-, medium-, and long-term hazards to health are detailed below for each of the main activities associated with coal-fired steam-generating power stations and the supplying of fuel to them. Quantitative data are provided wherever possible and care is taken to identify the data sources. While the amount of some pollutants is fairly accurately known, for others it is still a subject of speculation. The effect of some pollutants on health remains an even more speculative and often controversial subject in spite of the many studies that have been made. The situation is further complicated by the fact that pollution does not respect provincial or national boundaries, nor does electric-power generation contribute more than a fraction of the total. Thus, the impact of coal-fired power stations on the environment and on health must be assessed against a background of pollution that comes partly from fossil fuels which are burned for purposes other than electricity generation. Moreover, some of the impact of the operation of coal-fired power stations in Ontario will extend across the borders into other provinces and into the United States. Certain by-products, such as carbon dioxide and waste heat, will combine with similar by-products from other countries to have an impact on the global climate.

The Impact of Coal-Mining

Essentially all the coal that is used at present in coal-fired power stations in Ontario is imported from the U.S. or western Canada. The fact that the environmental and health impacts of mining this coal occur entirely outside the province is not a reason for discounting them.

The health impact of coal-mining, as well as of other parts of the coal fuel cycle, is discussed in Appendix C. Data from several interdependent review sources are tabulated in Table C.2 of that appendix. The validity of some of the data is also discussed in Chapter 8, where the impacts of various fuel cycles are compared.

According to the reference sources cited in Table C.2 it appears that the mining of coal for a 1,000 MW power plant (operating at a 75 per cent capacity factor), would result in approximately 0.5 to 5 occupational fatalities and 20 to 100 occupational injuries or disabilities (due to accidents and "black lung" disease). A total of 6,000 to 30,000 man-days would be lost to the industry. There would also be some fatalities and disabilities among the public, largely due to the disposal of mine tailings, particularly in places where current standards are not observed. Herbert Inhaber's[1] data predict 1 to 10 public fatalities and an unknown number of disabilities, but this is contested by J.P. Holdren[2] on the grounds that it is necessary to study the observance of regulations at the particular mines involved before arriving at quantitative conclusions.

Although the occupational risks of mining constitute their most spectacular impact, the effects of mines on the environment are no less a matter of public concern. These have to do with acid mine drainage, subsidence, and the disposal of wastes. Ontario is not directly affected by the environmental and health hazards of mining the bulk of the coal it uses, but, as public awareness increases, costly pollution-abatement measures are adopted in areas such as the Appalachian coal-mining region in the U.S., and these costs are reflected in the increased cost of coal to Ontario.

However, the exploitation of the Onakawana lignite deposits in northern Ontario[3] would have an increasing impact on the environment and on health within the province. Surface mining is inherently less hazardous to the workers than deep mining but the impact on the environment is severe. It is a

technology that can result in drastic changes to the environment. An area disturbed by mining seldom returns to the same ecological equilibrium that existed prior to the disturbance. The damage can be mitigated by careful monitoring of mining technologies, by the control of erosion and the prevention of damage to the hydrological system, and by such additional measures as soil reshaping, revegetation and, above all, by careful management.

The Ontario Ministry of the Environment sponsored preliminary studies[4] of the potential impact of the Onakawana strip-mining operations on soils, water, and the flora and fauna of the region. The following statement emphasized the importance of planning to minimize the environmental impact:

> It is emphasized that the key to success of all control measures is preplanning. With proper planning, many deleterious effects can be prevented, and others remedied with much less expenditure of time, effort and capital. Further, if the costs of environmental repair are estimated in the feasibility study they are budgeted as part of the cost of mine development and operation and do not subsequently arise as an unbudgeted cost.[5]

The conduct of such studies before significant development has taken place is to be applauded. It leads to the hope, indeed the expectation, that the deposits will be mined in such a way as to cause a minimum of permanent disruption of the ecology of the region.

Transportation of Coal

It is difficult to assess quantitatively the occupational, environmental, and public health impact of transporting the approximately 9 million tonnes of coal that were consumed in 1978 by coal-fired power stations in Ontario. The submission by Fisheries and Environment Canada to the RCEPP gave the following qualitative review of the subject:

> The present method of bulk shipment of coal to Ontario is by rail from the United States, and from Western Canadian coal fields by rail to Thunder Bay with trans-shipment to barge and then by barge down the Great Lakes. With the proposed increase in use of western coal to produce Ontario's electric power, the associated environmental impacts of shipping greater tonnage over this long system will be more severe, although just how severe has not been determined.
>
> With the prospect of increased traffic in coal trains, plans have been put forward to double-track the main CNR line across the prairies. This will consume, in total, a considerable amount of agricultural land and grassland. Other environmental factors of the rail transport of coal relate to the control of dust. Coal transport in open rail cars can release particulates to the air and result in non-fertile particle fallout on nearby lands. The light coal particles in the soil are susceptible to surface washoff, greatly increasing local soil erosion and stream sedimentation. Coal shipments are routinely sprayed with petroleum or chemical "binders" to reduce dust losses; the environmental consequences of this practice are not known.
>
> Although it is not directly an environmental impact, the health consequences of increased transport of coal by rail are a land-use concern. At present, level-crossing accidents involving coal trains are the most serious health problem of the coal industry in the U.S., greatly exceeding the accidents occurring in coal-mining. With increased coal transport, this problem can be expected to grow unless proportionally more investment is made and more land is dedicated to the construction of railways and highways.
>
> An alternative to rail shipment is pipeline transport. While a slurry pipeline offers some environmental [advantages over] rail transport, it has its own potential impacts associated with rupture of the pipe, water consumption, water and fines disposal, and land use for dewatering plants. Some coals may need chemical treatment of the slurry to prevent decomposition or excessive disintegration, and the removal of these substances or their oxidation during combustion could cause further problems. Coal-oil slurries may avoid some of these problems, but create others at the de-emulsifying plant. Much more study is warranted of the environmental aspects, including the potential advantages of coal piping techniques.
>
> The major environmental concerns related to developing enlarged trans-shipment facilities at Thunder Bay include land use requirements, dust and noise problems, and harbour dredging. Many of these concerns would be alleviated to varying degrees or avoided by the adoption of coal gasification, coal liquefaction, and slurry pipeline alternatives, but they may be traded for other concerns.
>
> Shipping the coal down the Great Lakes is not likely to present a significant environmental threat in the event of a shipping accident. However, the possibility of the leaching of toxic substances out of spilled or lost coal over a period of time does exist, which could affect fish habitats and spawning grounds.
>
> The soiling of property due to wind blown coal particles during storage and handling (the so-called

"windage loss") can be a severe local problem, and specific methods of dust suppression are necessary to keep it under control. There is the potential for dust from these sources to add significantly to the total particulate loading of the atmosphere over a considerable area. The extent to which airborne particles of coal dust can act as vehicles for transport and reaction of other chemicals released by a variety of sources is not known and needs careful research.[6]

In quantitative terms it is estimated (see Appendix C) that 1 to 2 deaths, and 1 to 20 occupational injuries may be attributed to the transportation of coal for a 1,000 MW coal-fired power plant operating at a 75 per cent capacity factor. If these U.S. figures are applicable, this would imply that the transportation of the amount of coal used for producing electricity in Ontario in 1978 would take an annual occupational toll (not all in Ontario) of 4 to 8 deaths and 4 to 80 disabilities, resulting in a loss of 22,000 to 80,000 man-days to the industry.

One study[7] quotes figures which would put the public (as opposed to occupational) toll at 2 to 5 deaths, 4 injuries, and 10,000 to 25,000 man-days lost due to transporting the coal for the generation of electricity in Ontario at current levels.

The figures quoted originated in U.S. publications and relate to U.S. experience. No comparable Canadian figures have been located. However, a Swedish study[8] estimates 4 to 5 deaths and 700 to 1000 injuries due to the mining and transportation of coal to produce 6 terawatt hours (0.685 gigawatt years) of electric energy. According to that study, about one-quarter of the deaths and consequences of injuries are related to transportation.

Converted into appropriate units, the Swedish figures would imply a total of 20 deaths and 3,000 to 4,500 injuries related to the mining and transporting of an amount of coal equal to that used in Ontario each year for the generation of electricity. The mortality rate agrees quite well with the U.S. figures. The injury rate differs, possibly because of a lower threshold level for the definition of "injury". Furthermore, the Swedish figures relate to European conditions which are not necessarily the same as North American conditions.

The Impact of Coal-Fired Electricity Generation

A coal-fired electric power station, in normal operation, can have a very considerable effect on the environment and on public health. The combustion of coal can be a major source of pollution, because the flue gases contain carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides, hydrocarbons, and some particulate matter. Moreover, almost 70 per cent of the energy derived from the coal emerges as waste heat, either from the stack or in the cooling water, and this can have deleterious effects.

Once the fuel is spent, the problem of disposing of the waste remains. It will be seen that the waste-disposal problem resulting from the burning of 9 million tonnes of coal a year is not inconsiderable. If care is not taken, dangerous chemicals will be leached out of slag heaps into the ground water, which ultimately may be used for animal or human consumption. Finally, the coal dust that becomes airborne during the handling of coal in such large quantities can cause serious problems.

Air Pollution: Quantities of Pollutants

Air pollution in Ontario towns is due mainly to automobile exhaust gases, the heating of buildings, and, in particular cases, industrial processes. It is a mixture of many chemicals, some of which are gaseous and some solid. The principal gaseous offenders are the oxides of sulphur, nitrogen, and carbon, but there are small quantities of many other substances. The contribution from coal-fired electricity-generating stations to air pollution is not easy to assess. L.A. Sagan[9] quotes studies that show that coal-fired electricity-generating stations are responsible for about 8 per cent of the total tonnage of U.S. air pollutants. Allowing for the different effects of various pollutants on health, he estimates that 62 per cent of the deleterious effects are due to sulphur dioxide, 20 per cent to aerosols, 18 per cent to oxides of nitrogen, and 0.1 per cent to carbon monoxide. However, this neglects the effects of trace quantities in the particulate component of flue gases of heavy metals and radioactive elements that are believed to cause a very small increase in the probable incidence of cancer in the general population (see the section on particulates below, and Chapter 8).

The most abundant and hazardous single atmospheric pollutant from coal is sulphur dioxide.

Sulphur Dioxide Emissions

An Ontario study[10] reported that about 478,000 tonnes of SO_2 were emitted by coal-fired electric power stations in Ontario during 1970, due to the consumption of a little more than 10 million tonnes of mainly high-sulphur U.S. coal. This corresponds to an emission factor of 47 kg/tonne which most sources quote as the factor appropriate to high-sulphur coal containing about 2.4 per cent sulphur by weight.

The emission factor can be reduced, either by the use of low-sulphur coal or by removing some of the sulphur content before or after combustion, but before the gases reach the atmosphere.

Although there are reserves of relatively low-sulphur coal in Canada, it has been regarded as a premium fuel to be used mainly for industrial applications in which the low sulphur content is important. Consequently, the bulk of the coal imported to Ontario for coal-fired power stations is likely to have a high sulphur content. The Onakawana lignite has a sulphur content of only 0.5 per cent by weight but this is regarded as equivalent to 1.3 per cent on an equal-energy basis, thus giving an emission factor in terms of electricity generated of about 55 per cent of that of Appalachian coal.

The most practical way of reducing the emission of sulphur oxides from coal-fired power stations is the use of "scrubbers" to desulphurize the flue gas before it emerges. This is a costly process in terms of capital investment and operating costs, and it causes some reduction of conversion efficiency.

While there is no flue-gas desulphurization (FGD) equipment in regular operation in Ontario power stations, the programme of desulphurization is well under way in the United States. According to the latest report (November 1978), out of a total coal-fired generating capacity of about 265 GW, 16 GW has operational FGD equipment, 17 GW has FGD equipment under construction, and 29 GW has FGD equipment in various stages of planning.[11] In unit terms there are 46 FGD units in operation, 43 under construction, and 55 planned.

The measured efficiency of sulphur removal in 22 U.S. installations showed a spread of 50-97 per cent with a weighted average of 78 per cent. The adjusted cost of the installations varied according to type and according to whether the installation was new or retrofitted. The capital costs were within the range \$56-222/kW, with an average of \$94/kW, except for regenerable and magnesium oxide units which cost approximately double. The figures are in U.S. dollars. In Canadian terms, a 2,000 MW station such as Nanticoke would cost \$200 million to retrofit with scrubbers, assuming a factor of \$100/kW.

Adjusted annual operating costs for 16 installations varied from 2.6 to 12.7 mills/kW·h with an average of 5.5 mills/kW·h. This represents an addition of about \$10 a month to the average electricity bill.

Even the determined desulphurization programme in the U.S. will have equipped only 16 per cent of the total installed capacity in the U.S. with FGD units by the year 1987, according to current estimates. Moreover, one of the problems is to maintain these units in day-in day-out operation. The U.S. records[12] show that there is a wide variation in the reliability and operability of FGD installations. On the average, therefore, the amount of sulphur removed from flue gases is substantially less in practice than is suggested by the installed FGD capacity.

Using the average figure for U.S. installations, it would currently cost a total of \$1 billion dollars to install FGD equipment on the 8.94 GW of existing coal-fired electric power installations in Ontario. However, if the U.S. experience is indicative, the work would be spread over many years and costs would rise progressively with inflation.

There are those[13] who hold that the best and cheapest way to minimize the environmental and health effects of sulphur is not to remove it from the flue gases but rather to dissipate it in the atmosphere from high, specially-designed chimneys. This generally increases the dilution of the gas at breathing levels to a point where it is said to be quite harmless to human beings and actually beneficial to plants. To quote one source: "FGD is a technology looking for a problem to solve."[14] The merits of this case will be discussed further in the section dealing with flue gases.

Oxides of Nitrogen

When coal is burned the nitrogen in the air and any present in the fuel can combine with oxygen to form oxides of nitrogen, some of which are demonstrably harmful – at least in high concentrations.

Estimates from several sources of the amount of oxides of nitrogen in the flue gases of coal-fired power stations indicate that a representative emission factor would be 7.5 kg/tonne. Using this factor, it appears that some 68,000 tonnes of oxides of nitrogen were emitted by Ontario coal-fired power stations in 1978, based on the consumption of 9 million tonnes of coal.

Fisheries and Environment Canada[15] estimate that coal-fired power stations contribute about one-sixth of the total atmospheric load of oxides of nitrogen. Most of the contribution comes from automobiles, and the oxides appear in high concentration mainly in urban areas.

The emission of nitrogen oxides is more difficult to control than that of sulphur dioxide. Control is usually attempted by modification of the combustion process rather than by the addition of an apparatus comparable to the scrubber. Such modification is not without its side-effects, such as corrosion of heat transfer surfaces and increased operating costs. Satisfactory solutions are still being sought. It is therefore difficult to predict the cost of nitrous oxide abatement measures.

Moreover, the impact on the environment and on health of nitrogen oxides in the concentrations that now exist is still not fully understood, nor is there any precision in the estimates of its magnitude. Current views on the health and environmental impact are reviewed in the section dealing with flue gases. The lack of knowledge of the extent to which nitrogen oxides from coal-fired power stations contribute to environmental and health hazards naturally reduces the incentive for utilities to develop or introduce expensive measures to reduce the emissions of nitrogen oxide.

In spite of these considerations, Ontario Hydro has experimented with control measures for nitrogen oxides and used them in a limited way from time to time, but no startling reduction of the total emissions can be anticipated with technology that is currently available. One reference[16] quotes U.S. figures suggesting that new technology, not yet developed, may achieve a reduction of as much as 60 per cent in nitrogen dioxide emissions from coal-fired power stations in the U.S. by the year 2000.

Particulates

All types of coal contain minerals that appear after combustion as ash – either as bottom ash (about 20 per cent), or as fly ash (about 80 per cent), which is carried out by the flue gases. Most of the fly ash is removed by mechanical or electrostatic precipitators. In a report[17] on U.S. installations of desulphurization equipment, the measured efficiency of the associated electrostatic precipitators is often as high as 99.9 per cent. However, not all generating stations in Canada are equipped to this standard, and an average efficiency of 99.0 per cent would be more realistic. Using this figure for a coal with 15 per cent ash content would result in a total particulate emission of 13,500 tonnes per annum from the 1978 consumption of coal by the generating stations of Ontario. The difference between 99.9 and 99.0 per cent may not appear to be great, but it represents a factor of 10 difference in the amount of particulate emissions.

The particulates that get past the electrostatic precipitators tend to be very small and in the respirable range. They can carry many of the trace elements found in coal ash, including lead, cadmium, selenium, nickel, arsenic, molybdenum, boron, uranium, copper, tin, and mercury. Ontario Hydro has been concerned about these emissions for many years[18] and has conducted studies of them. Their impact is not easy to distinguish, because the bulk of heavy metal emissions come from other sources, such as automobile exhausts. The possible environmental and health impact of particulates is discussed in the section on flue gases.

Carbon Monoxide

About half a kilogram of carbon monoxide is emitted for every tonne of coal consumed in a coal-fired electricity-generating plant[19] in spite of efforts to make the combustion process as complete as possible. However, the amount is very small compared with that produced by natural processes and by automobiles. Unlike power plants, automobiles produce dangerous concentrations near ground in densely populated areas.

For example, it is estimated[20] that the carbon monoxide emitted by coal-fired power plants in the U.S. is less than 0.2 per cent of the total U.S. emissions. The proportion in Ontario is probably similar. In 1970 Ontario Hydro estimated that 0.13 per cent of the total carbon monoxide concentration in the city of Toronto came from the R.L. Hearn Generating Station and 0.24 per cent from the Lakeview Generating Station. Moreover, the residence time of carbon monoxide in the atmosphere appears to be only about one month[21], after which it dissipates harmlessly. For these reasons, carbon monoxide emissions from electric power plants are not discussed further as a significant threat to the environment or to public health.

Carbon Dioxide

The principal constituent of the flue gases from a fossil-fuelled power station is carbon dioxide. As much as 5 million tonnes a year is emitted for every 1,000 MW of generating capacity.[22] While the carbon dioxide is not harmful in itself, it is discharged into the atmosphere where, together with discharges from other sources, its concentration slowly but steadily increases. While this accumulation poses no local or regional threat to health or the environment, it could have a gradual effect on world climate, as described in the opening section of this volume, and thus is a matter for increasing concern.

Flue Gases: Environmental and Health Impact

The approximate amounts of potentially harmful constituents of the flue gases from coal-fired electric power plants have been discussed above. The data are summarized in Table 2.1.

Table 2.1 Summary of Constituents of Flue Gases from Coal-Fired Generating Stations

Constituent	Typical emission factor Kg/tonne	Approximate[a] total emission in Ontario (tonnes/year)
Sulphur dioxide	47[b]	423,000[c]
Nitrogen oxides	7.5[b]	67.500
Particulates	1.5[b]	13,500
Carbon dioxide	–	15,000,000
Carbon monoxide	0.5	4,500

Notes:

a) Based on burning 9 million tonnes of coal to produce 3.091 GW•years of energy (1978 figures: see Table 1.1).

b) Correspond to the actual emission factors for Lakeview. G.S. in 1970, which may be pessimistic for the current mix of western and Appalachian coal.

c) Without abatement measures.

Source: RCEPP.

It should be noted that the particulate emissions include a small quantity of radioactive elements. While the level of radioactivity is low and differs in nature from that from the stacks of nuclear power stations, thus making comparison difficult, it can reach levels that are believed to contribute significantly to the impact of the emissions on health.

The data in Table 2.1 are necessarily approximate when related to current emissions, because they fluctuate according to the type of coal, the type of furnace, and the extent of use and effectiveness of flue-gas treatment. Nevertheless, they are a model of precision compared with the estimates of the environmental and health impact they produce. Much more research needs to be done on the environmental and health impact of the various constituents of polluted air and on the contribution to total air pollution by the emissions from coal-fired electricity-generating plants.

The results of several studies will be summarized and compared in this section. It is a controversial subject and one in which few definitive answers can be derived from present data. An effort is made to identify particular areas in which further research is needed.

The Direct Impact of Gaseous and Particulate Emissions

The impact on the environment and on public health of the many thousands of tonnes of sulphur dioxide and particulates that are emitted from the stacks of coal-fired electric power plants in Ontario is far from negligible.

Sulphur dioxide is known to cause irritation of the bronchial tract when it is present in sufficient concentration. The Canadian Air Quality Objectives (which are approximately the same as their U.S. counterpart) suggest maximum concentrations of 0.34, 0.11, and 0.02 ppm averaged over one hour, one day, and one year, respectively. There are similar guidelines for nitrous oxide (0.21, 0.11, and 0.05 ppm) and for particulates (120 g/m^3 averaged over one day or 70 g/m^3 averaged over one year). However, relating the effect of stack emissions from power stations to these guideline concentrations for inhabited areas is a very complex process.

The concentration of contaminants in the air we breathe is due to the burning of fuels (not only coal) for many purposes (not only electricity generation) in many places (not only Ontario). A significant proportion of the pollution in the air over Ontario comes from industries and utilities outside the province (e.g.,

in the U.S. near the Canadian border). Pollution is no respecter of provincial or national boundaries. It follows that some of the products of combustion from Ontario industries and utilities have effects outside the province, e.g., in the province of Quebec.

Moreover, the impact of one component of polluted air (e.g., sulphur dioxide) can be obscured by or combined with the impact of another (e.g., nitrogen oxides or particulates), so that it cannot readily be estimated separately.

Ramsay summarizes the situation as follows:

> . . . it is very difficult to determine how many deaths and illnesses are caused by the usual levels of air pollution, and doubly difficult to decide what the air-pollution-related effects of adding one more coal-fired plant to an electrical generating grid would be. One way of approaching the problem is to examine mortality statistics and reports of illnesses, relating fluctuations in them to fluctuations in air-pollution levels. And studies have been done that relate sulfur dioxide or sulfate levels to recorded health statistics. But the results have been exceedingly controversial, since the nature and extent of the air pollutants themselves are poorly known, or only spottily measured, and the timing and causes of death and illnesses are difficult to correlate. When other factors are included, such as weather, movement of populations, and all the other variations in people, economics, and geography that complicate interpretations of health statistics, the difficulties become apparent.[23]

However, in spite of these difficulties, attempts are continually made to assess the nature of the potential hazards and the magnitude of the impact on the environment and public health.

The sulphur dioxide emitted from power plants tends to change into other sulphur compounds in the atmosphere, combining in turn with the very small particles of fly ash that escape from the electrostatic precipitators. Tests on animals have shown[24] this combination to cause greater difficulties in breathing than sulphur dioxide alone at a similar concentration. It is clear that the average concentration of sulphur dioxide, even in the cities, is only a small fraction of what it takes to aggravate bronchial problems. However, local concentrations can exceed the limits under certain atmospheric conditions. There are many uncertainties. The attempts to correlate asthma, respiratory diseases, heart-lung symptoms, and even premature deaths, from recorded health statistics, to air pollution are extremely controversial. There is particular uncertainty concerning the effects of prolonged exposure to low concentrations of such pollutants. This is also true of the impact of the trace elements that occur in the particulate emissions, some of which are toxic or radioactive or are known or suspected carcinogens. The effects of these and of the hydrocarbon benzopyrene, which is often found in coal effluents, in contributing to cancer, will only be evident after many years and will be very difficult to distinguish from the effects of airborne carcinogens from other sources.

Some researchers believe that traces of metals and metals compounded with sulphur are responsible for all the observations relating to the deleterious effect of air pollution on the lungs. To quote R.W. Ross:

> The conclusion is that the sulfate ion is harmless, and it is what goes with it that counts.
>
> No case can be made for limiting SO_2 emissions from properly-designed tall-enough stacks on the grounds of sulfate formation and health.[25]

The same source observed that "flue-gas desulfurization is a technology looking for a problem to solve; it is not needed for health reasons; as a cure for acid rain its success is unpredictable and its cost is 500 times greater than a predictably successful procedure (i.e., the design of tall chimneys)."[26] These views are not universally shared. Some of the efforts to quantify the health impact of the emissions from coal-fired power stations are summarized in the following sections.

The environmental impact is manifested in several ways. Nitrogen dioxide is a brown gas and, together with particulates, is visible in the air in certain concentrations; it is aesthetically objectionable. Crop damage has been observed in areas of high atmospheric pollution. But the most serious environmental problems that are associated with the presence of the oxides of sulphur and/or nitrogen in the air are those of acid rain and ozone.

Acid Rain

During the last few decades the acidity of the precipitation in Ontario has shown a marked increase. A similar increase has been observed in the northeastern United States and in many parts of Europe. While it is difficult to trace all the processes that result in the increased acidity of rain, sulphur dioxide and the oxides of nitrogen are believed to be principal culprits, in the ratio of 2 to 4:1. When emitted from the stacks of coal-fired power stations, or industrial plants, the oxides combine with moisture in

the air to form dilute acids of sulphur and nitrogen. The reaction takes time (estimated at 0.4 to 12 per cent oxidation per hour) and the acid precipitation generally occurs at distances of up to 1,500 km from the polluting source. For example, much of the acidity in precipitation falling on Ontario originates in industrial areas south of the U.S. border. The effluents from Ontario plants can produce acid precipitation in Quebec and Labrador. Consequently, acid rain is not a problem that can be solved by unilateral action within a single region. Acid rain has several effects on the environment, the most serious of which is the damage caused by increased acidity to the life in Ontario lakes. Fish and most other aquatic life cannot survive when the acidity increases above a certain level. The vulnerability of a lake depends upon the nature of its geological environment. Lakes in areas with limestone bedrock (e.g., most of southern Ontario) are much less vulnerable than those in insoluble Precambrian bedrock which includes much of central and northern Ontario. Figure 2.1 illustrates the susceptibility to acid rain of the lakes in three areas of Ontario, according to a recent study.[27] Sweden reports[28] a similar phenomenon due largely to effluents from plants in more southerly European countries. Some 10,000 of Sweden's 100,000 lakes are already affected. Fig. 2.1: p.

Persistent acid rain can also cause damage to buildings and other structures and to many types of surface finish. Copper plumbing is also susceptible at the levels of acidity that are encountered in some areas.

The effect of the acidity resulting from the effluents of power plants on human health is not accurately known. Ramsay reports that "it has been found in tests on laboratory animals that related compounds of sulphur, inhaled in the form of droplets or carried on very small solid particles, can cause five to 20 times as much difficulty in breathing (as measured by airflow resistance) as does sulphur dioxide itself."[29] The minute particles in the effluent contain trace metals and, according to another report, "there is considerable medical data linking acidity with the greater activity and toxicity of trace metals".[30]

The present state of knowledge of these effects does not permit a quantitative evaluation of the health effects of acid rain.

The principal sources of the sulphur dioxide and nitrogen oxides that are the cause of acid rain in Ontario are in the northeastern United States and in Ontario itself. For instance, it is thought[31] that about 80 per cent of the acid precipitation in the Haliburton area is attributable to U.S. sources.

Of the Canadian effluents that may cause acid rain, about half come from the International Nickel Company plants in Sudbury and a good part of the remainder from coal-fired power plants. While industrial and power plants are the principal contributors of sulphur dioxide, a great deal of the nitrogen oxides in the atmosphere comes from other sources such as automobiles and furnaces.

There are only two ways of handling the acid rain problem. One is to reduce the emissions of sulphur dioxide and nitrogen oxides from all sources. The other is to apply some kind of treatment to the affected areas.

In other countries, some[32] take the view that the pH level of susceptible lakes could be maintained by the application of lime as a buffering agent to neutralize the effect of the acid. Experiments in Ontario[33] tend to show this to be effective as a preventive measure but not one that is capable of restoring a damaged lake to its former chemical and biological state. Moreover, the treatment of all the lakes in Ontario that are susceptible to deterioration by acid rain is neither physically nor economically practical. Such treatment would, at best, be confined to selected areas of economic, environmental, or historical importance. Consequently, the only solution appears to be the treatment of flue effluents to minimize the emission of the offending gases. The enormous cost of applying such measures to the coal-fired power stations in Ontario was discussed above. Such action would be useless unless accompanied by similar measures for the equivalent sources in the United States.

The problem of acid rain requires draconian measures to mitigate it. It has been pointed out that the dynamic and costly U.S. programme[34] will equip only 16 per cent of all U.S. coal-fired electricity plants by the year 1987 and there are as yet no plans for applying equivalent control technology in Canada. We therefore endorse the recommendations of the report[35] of the Standing Committee on Resources Development of the Ontario Legislature, particularly those that call for co-operative action by Canada and the United States.

Ozone

Ozone (O_3) is not a significant constituent of flue gases from coal but it is produced in the atmosphere as a result of the presence of nitrogen oxides and hydrocarbons in the flue emissions.

Nitrogen dioxide (NO_2) is dissociated by sunlight into nitric oxide (NO) and a single oxygen atom (O) which then combines with oxygen (O_2) to form ozone (O_3). The ozone and nitric oxide are able to recombine into nitrogen dioxide and oxygen. The equilibrium between these two reactions is upset by the affinity of the oxidized compounds of hydrocarbons to nitric oxide, which also leads to the production of nitrogen dioxide. The net effect is to shift the dynamic equilibrium of the system in favour of the production of more ozone.

Naturally, there is an observed increase in ozone levels during the day-time and a decrease at night. A study[36] by the Radioactivity Management and Environmental Protection Department of Ontario Hydro has correlated this with the daily variation in sunlight in industrial areas of the northern United States, suggesting that the bulk of the ozone present near Bruce is not produced locally.

The Ontario Ministry of the Environment has established 80 parts per billion (ppb) as the desirable hourly air quality criterion. Their measurements in various Ontario locations are shown[37] in Table 2.2.

Table 2.2 Monthly Average Ozone Levels (ppb)

	June	July	August
Toronto (College St.)	25.6	26.9	19.3
Ottawa	24.8	27.2	20.7
Sarnia	26.0	30.0	22.5
London	29.5	35.8	28.8
Simcoe (Experimental Farm)	48.8	53.3	42.4
Inverhuron Park	31.3	33.9	31.8

Source: E. Laretta. "Ozone Concentration at Inverhuron Park, June to August 1977". Toronto: Ontario Hydro, March 1978.

The recommended maximum level of 80 ppb is, however, exceeded in Toronto for nine hours in every thousand and in Simcoe for 72 hours in every thousand. This is thought to be due to the fact that Simcoe is downwind from large urban-industrial centres near the south shore of Lake Erie.

The effects of ozone can be very serious if the concentration is high. Ozone is a strong oxidizing agent that can cause injury to leaves and decrease plant growth. One source[38] indicates that damage can occur by exposure to a concentration of as little as 100 ppb for several hours.

Farmers in Essex and Kent counties in southwestern Ontario have been phasing out production of white beans in favour of crops less susceptible to air pollution, and effects have been noted by various scientists in the Norfolk County area. The most susceptible crops appear to be white beans, tobacco, and tomatoes.

The constituents of oxidant smog can travel great distances with air masses and all of southern Ontario is occasionally blanketed in oxidant smog, which can damage sensitive crops. The development of supplementary sources of these constituents in southwestern Ontario could affect these concentrations substantially in some areas.

Ormrod, Hofstra, and Humphreys, of the University of Guelph, conducted a systematic study of oxidant smog (ozone) across western Ontario during the summer of 1976 to determine the characteristics of ozone episodes in relation to weather factors, and to determine to what extent Huron County was affected. Ormrod commented: "Development of an urban and industrial area associated with a power plant on the shoreline of Huron County would probably affect the concentration of oxidant smog in the County".[39] He stated that the oxidant damage to crops is dependent on environmental factors such as rainfall, temperature, and humidity and that more damage can be expected near the Great Lakes because of the high humidity. Areas with the highest seasonal rainfall and the warmest temperatures would be expected to have the most crop damage. He also cited studies to show that yields of tomatoes, corn, and soybeans can be reduced by as much as 45 per cent by oxidant levels found near urban areas.

Ormrod observed that, generally, when levels were high in one location in southern Ontario they were also relatively high at other locations. Daily ozone concentration patterns varied considerably from place to place. In general, ozone was borne from west to east, reaching peaks in Michigan a day earlier than in Kippen, and peaking in New York State a day later. In general, air pollution peaks occurred when high-pressure areas centred over Quebec, drawing warm southwesterly flows of air up from the

U.S. Midwest over southwestern Ontario. With the passage of the weather front, ozone levels dropped sharply.

In Huron County, injury of tobacco plants was observed following the high ozone levels in June 1976. Beans were bronzed across Huron County following the pollution on August 20-22 of that year.

In general, ozone reaches its peak downwind of large urban centres. Chicago, Detroit, Toledo, and Cleveland would all have made a contribution to the ozone episodes charted by Ormrod. The development of large industrial centres in southwestern Ontario could well contribute to the concentrations of air pollution over foodland areas. To quote Everett Biggs:

> Kent County at one time produced close to 40 per cent of the white bean crop in Ontario and new produces about 5 per cent . . . significant in that production shift was the fact that yields were reduced as a direct and measurable consequence of air pollution in that green and lively rural country.[40] In Ontario, losses from this cause are estimated at $25 million over the last 20 years for tobacco and $3 to $4 million over the last five years for white beans.[41]

The most important area requiring new and continuous air pollution research is the development of air-quality criteria and standards with respect to vegetation. Standards are needed to prevent agricultural and forestry losses, to maintain cover crops against erosion, and to preserve the aesthetic appeal of ornamentals and the landscape. Research is needed on time-concentration (dosage) experiments, the interaction of pollutants, the effects of toxic concentrations of elements, the interaction between air pollutants and water nutrients, pathogens, herbicides, and pesticides, and the formation of photochemical oxidants in non-urban areas.[42]

Because much of the ozone that appears in Ontario is a result of emissions from U.S. plants, the ozone problem, like the problem of acid rain, will yield only to a co-operative approach by the U.S. and Canada. Measures to reduce the emission of nitrogen oxides are not well developed in North America, but some other countries such as Japan are, perhaps, farther advanced because the need was evident at an earlier stage due to the very high concentrations of pollution-emitters in a relatively small geographical area.

Impact of Air Pollution on Public Health

Ramsay[43] has published quantitative data related to the probable impact of generating 1 trillion kW·h (228 GW·years) in coal-fired power stations in the United States in 1975. Figure 2.2 uses Ramsay's method of graphical presentation. The number of events in each bar chart is scaled to correspond to the generation of 3.091 GW·years – the amount of electric energy that was produced by coal-fired power plants in Ontario in 1978. Scaling down from U.S. data has dangers, especially when dealing with respiratory diseases that result from air pollution. Clearly, the impact depends upon many factors, not the least of which is the proximity of power plants to populated areas. Nevertheless, Ontario Hydro data related to the concentrations of flue gas effluents in Toronto are quite similar to those found in urban locations in the U.S. Moreover, the uncertainties represented in the bar charts of Figure 2.2 are likely to be much greater than those inherent in the scaling process. The shading of the bars is intended to represent a reduction of confidence in the higher figures and must, of course, be interpreted in this way for the mortality diagram. However, in the diagrams relating to respiratory diseases and aggravated heart-lung symptoms, it is perhaps more convincing to think of the shading as representing the intensity of the attacks, because in gathering health statistics it is always difficult to draw the line at which the symptoms are negligible.

Fig. 2.2: p

Of course these deaths and illnesses are those that may be added to the normal level by the extra pollution emitted from the flue-stack effluents from coal-fired power stations. Interpreting them conservatively, it seems that air pollution from coal-fired power stations may be responsible each year for a few additional deaths, thousands of additional cases of respiratory disease, thousands of asthma attacks, and tens if not hundreds of thousands of extra man-days of aggravated heart-lung symptoms, particularly in the elderly.

Impact of Coal Storage, Power Plant Effluents, and Waste Disposal

The storage and handling of coal at power plants requires careful control to minimize wind-blown particles and the effects of coal-pile drainage.

Wind-blown particles of coal can cause problems both by soiling local property and by adding considerably to the total particulate loading of the atmosphere over a wide area. The coal particles can act as

nuclei for other atmospheric contaminants and thus increase their potential for creating health problems when they are breathed in.

Significant quantities of solid waste are left after combustion (bottom ash), from fly-ash precipitators, and from flue-gas desulphurization equipment, if it is used. For example, the total ash residue from burning 9 million tonnes of coal to generate electricity in Ontario in 1978 was close to 1 million tonnes. Flue-gas desulphurization would greatly increase the amount of solid residues, thus exchanging an air-pollution problem for other problems concerned with waste disposal and water pollution. Currently, however, in the absence of FGD equipment, the most abundant wastes are retained fly ash and bottom ash.

Rainwater penetrating through ash-heaps washes out the heavy metals they contain and may cause pollution of the subsoil water and have an undetermined long-term effect on the environment and on human health. This is true whether the ash is laid up or disposed of in land-fill sites as is the common practice in Ontario. Fisheries and Environment Canada couch their warning in the following terms:

> Given a particular hydrogeological setting, and climatic conditions conducive to leachate generation, a significant environmental impact from contaminant loadings to receiving waters is possible. It seems clear that leaching and run-off must be minimized and controlled to assure that groundwater or stream pollution does not occur.[44]

Canada has not yet significantly exploited the possibility of extracting valuable industrial minerals such as vanadium and nickel from the ash or exploited its potential use as a basic construction material. It is used in Europe to a considerable extent as an aggregate for coal asphalt, as a component in light concrete, and as a road-base aggregate.[45]

Local problems can also be caused by miscellaneous discharges from the plant during normal operation. The "Generation-Environmental" submission of Ontario Hydro to the RCEPP stated:

> In keeping with The Objectives for Water Quality Control in the Province of Ontario and the overall policy of protecting water quality while recognizing essential use for waste water disposal, the Ministry of the Environment requires Ontario Hydro, along with industry, discharging wastes into watercourses, to limit, destroy, remove or modify any waste constituents that may be in question. This may apply to waste constituents that are not readily removed by conventional treatment and are only reduced by dilution and other natural stream purification processes.

These wastes include:

- Oily water
- Boiler water treatment plant effluents
- Ash-sluicing effluent
- Boiler and wash effluent
- Coal-pile drainage
- Ash disposal area drainage
- Air preheater wash effluent
- Sewage lagoon effluent[46]

It is important to ensure that the standards that are set for the disposal of such effluents are adequate for the long-term protection of the environment and of health and that they are meticulously observed and rigorously monitored.

Environmental and Health Impact of Coal Conversion Processes

Processes for coal liquefaction and gasification are described in Volume 4 of this Report. Much of the research and development of these processes has been in the United States. The recent U.S. decision to accelerate the substitution of coal for oil will no doubt intensify the work. The coal will be converted into liquid or gas near where it is mined and transported by pipeline to the point of use. Such processes have not yet been introduced in Ontario on any scale because they are more costly than the conventional process and introduce a net energy loss.

From an environmental point of view, the principal effect of using a coal-gasification process would be to move most of the pollution from the site of the power plant to the site of the conversion plant. Since almost all the coal used in Ontario electric power plants is imported, much of the pollution would be exported out of the province.

Air pollutants from a coal gasification plant are quite similar to those from burning coal in a conventional power station, and the methods for controlling emissions would be essentially the same as those

discussed in the section on flue gases. However, there will be some minor differences between the types and quantities of pollutants produced by different processes, depending on the nature of the coal, the final temperature of the process, and the details of the process.

A great deal of water is used in the gasification process and the raw gas cooler exit stream will contain a large number of pollutants, the nature and quantity of which will depend on the process. Contaminants include oils and phenols, ammonia, sulphides, cyanides, thiocyanates, and suspended solids. This necessitates large-scale treatment, possibly including biological oxidation, absorption, filtration, and ion exchange, before the water is discharged into the environment.

A large amount of solid waste has to be disposed of at the conversion plant, consisting mainly of ash, slag, and the products of desulphurization. If the ash is not returned to the mine, large areas of land may have to be removed from use to provide permanent storage for it. Depending on the composition of the ash, the local topography, and the nature of the ground and surface waters, provision will have to be made to prevent leachable salts from entering either the ground-water or the surface-water system.

It has been said that the accumulation of ash from 40 years' operation of a 1,000 MW coal-fired power station would "occupy an area of 1 km^2 to a depth of several tens of metres".[47] The accumulation at a coal-gasification plant would be at a similar rate, unless steps were taken to use the ash as land fill, put it back in the mines, or find other uses for it.

Coal-conversion plants producing liquid instead of gaseous fuel are also being considered as an alternative to direct combustion. While the process differs from coal gasification, it will produce a comparable range of gaseous, liquid, and solid wastes.

The Total Impact of Coal

There have been a number of reviews of statistics on the health impact of coal-fired power plants in terms of numbers of fatal or disabling events due to disease or accident or of the number of man-hours lost. Because these reviews do not always arrive at the same figures, the data from a few principal review papers are compared and reviewed in more detail in Appendix C.

Ramsay states: "... here, we detail the total number of fatalities expected if U.S. electrical requirements for 1975 had been supplied by coal alone (1 USW); ranging from 200 to 9,000 fatalities, they reflect especially the uncertainties in air pollution effects. Nonfatal illnesses and accidents from occupational causes (20,000 to 40,000 per USW) can be compared with the pollution illnesses ... : 100,000 to 10 million asthma attachs; 600,000 to 60 million person-days of aggravated heart-lung symptoms in the elderly; 60,000 to 6 million cases of chronic respiratory disease in adults; and 10,000 to 1 million cases of lower respiratory tract disease in children."[48]

Elsewhere Ramsay defines 1 USW as 2 trillion kW·h, which is equal to 228 gigawatt years. In 1978 Ontario produced 3.091 gigawatt years of electric energy from coal. Thus, crudely, we could scale down[49] Ramsay's figures by a factor of 228/3.091 = 73.76 to arrive at an idea of the total impact of the coal-fired plants in Ontario. These figures are tabulated in Table 2.3.

Table 2.3 Estimate of the Health Impact of Coal-Fired Power Plants in Ontario[a]

Impact	Estimated number of occurrences
Fatalities[b]	2.7–122
Occupational illnesses and accidents (non-fatal)	271–542
Coal-related asthma attacks	1,356–135,600
Man-days of aggravated heart-lung symptoms	8,134–813,400
Chronic respiratory diseases (adult)	813–80,134
Lower respiratory tract diseases (children)	136–13,600

Notes:

a) Based on data from "Unpaid Costs of Electrical Energy", W. Ramsay, p. 121, prorated to the total amount of electric energy generated in coal-fired plants in Ontario in 1978.

b) Including mining and transportation impact outside Ontario.

Source: Based on W. Ramsay, "Unpaid Costs of Electrical Energy", and other U.S. data.

Ramsay's data includes the impact of mining accidents and occupational diseases, such as black lung pneumoconiosis, transportation accidents, and air pollution. He breaks down the fatalities as follows (scaled down by the same factor as in Table 2.3.):

Air pollution with best available control technology – 0 to 27
Air pollution without best available control technology – 0 to 95
Occupational – 1.35 to 13.5
Other – 2.7 to 27

A report to the Council on Scientific Affairs of the American Medical Association (AMA)[50], largely based on the review by Comar and Sagan[51], quotes estimates of the health effects of the coal fuel cycle for a 1,000 MW power plant. As the U.S. figures are based on the assumption of a 75 per cent capacity factor this would correspond to 750 MW average output, or 0.75 GW·years energy per annum, which is almost exactly one-quarter of the electric energy generated from coal in Ontario in 1978. Table 2.4 has been calculated from Table I in the AMA paper mentioned above by multiplying all figures by a factor of 4. It gives a rather higher figure than Ramsay: 72 to 1,658 total fatalities per annum (2 to 32 occupational and 70 to 1,626 public). The figures for occupational injuries and diseases are quite comparable at 104 to 624 (AMA) against 271 to 542 (Ramsay). Both sources agree that most of the non-occupational deaths are due to air pollution, but no figures for non-occupational non-fatal diseases due to air pollution are given in the AMA paper. However, Comar and Sagan[52] in the AMA paper referred to above quote even higher maximum figures than Ramsay's for the probable impact of air pollution on health. In spite of the enormous range of uncertainty that is apparent in the above figures, there are some who believe the minimum figures are still too high and others who believe the maximum figures are too low. Further discussion of these data appears in Chapter 8 and Appendix A. The figures selected for comparison with the nuclear fuel cycle in Chapter 8 are similar to those in Table 2.4 except that a more modest estimate of the upper limit of public fatalities due to air pollution has been used, in order to accommodate the recent comments of Holdren et al.[53]

Table 2.4 Estimate of Health Effects of Coal Fuel Cycle[a] (per annum for Ontario coal-fired electricity generation)

	Occupational deaths		Occupational injuries and disease		Non-occupational deaths	
Process	**Accident**	**Disease**	**Accident**	**Disease**	**Accident**	**Disease**
Extraction	1.8–5.0	0–19	88–320	2.4–192	–	–
Transport	0.2–7.6	–	1.3–92	–	2.2–5.2	–
Processing	0.8–0.2	–	10.4–12.4	–	4–40	–
Generation	0.4–0.12	–	3.6–6.0	–	–	0.27–1,212
Total	2.2–32		104–624		70–1,656[b]	

Notes:

a) Based on Table 1 of "Report C(A-78) of the Council of Scientific Affairs", AMA, June 1978, multiplied by a factor 4 to correspond to the 3.091 GW·years of electric energy generated by coal-fired stations in Ontario in 1978. (The above table is based on only one of the available references. See Appendix A for a comparison of figures from several references.)

b) No explanation is given in the original reference for the discrepancy between these figures and the sum of the entries above them. They may include deaths from other causes than air pollution. The figures 0.27 - 1,212 are specifically identified with the latter.

Table 2.5 Annual Impact of 1,000 MW Coal-Fired Power Station (75 per cent capacity factor assumed) (Environment, Wastes, Emissions)

Activity	Impact	Amount	Unit
Mining[a]	Land disturbance	1.9	km^2
	Land subsidence	1.1	km^2
	Mine drainage	10,000	tonne
	Sulphuric acid in drainage	80	tonne
	Dissolved iron	20	tonne
Generation	Fuel consumption[b]	2,200,0000	tonne
	Bottom ash[b]	44,000	tonne
	Fly ash retained[b]	220,000	tonne
	Sulphur retained[b]	–	
	Waste storage area[a]	5	km^2
	Thermal discharge[a]	1,000	$MW \cdot year_{th}$
	Stack discharge[a]	194	$MW \cdot year_{th}$
	Air Emissions (Typical)		
	fly ash	2,000	tonne
	SO_2	103,000	tonne
	CO_2	4,400,000	tonne
	CO	1,100	tonne
	NO_x	16,500	tonne
	Hg	5	tonne
	Be	0.4	tonne
	As	5	tonne
	Cd	0.001	tonne
	Pb	0.2	tonne
	Ni	5	tonne

Note: Mining impact mainly outside Ontario.

Sources:

a) "Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy." U.S. Atomic Energy Commission Report WASH1224, December 1979.

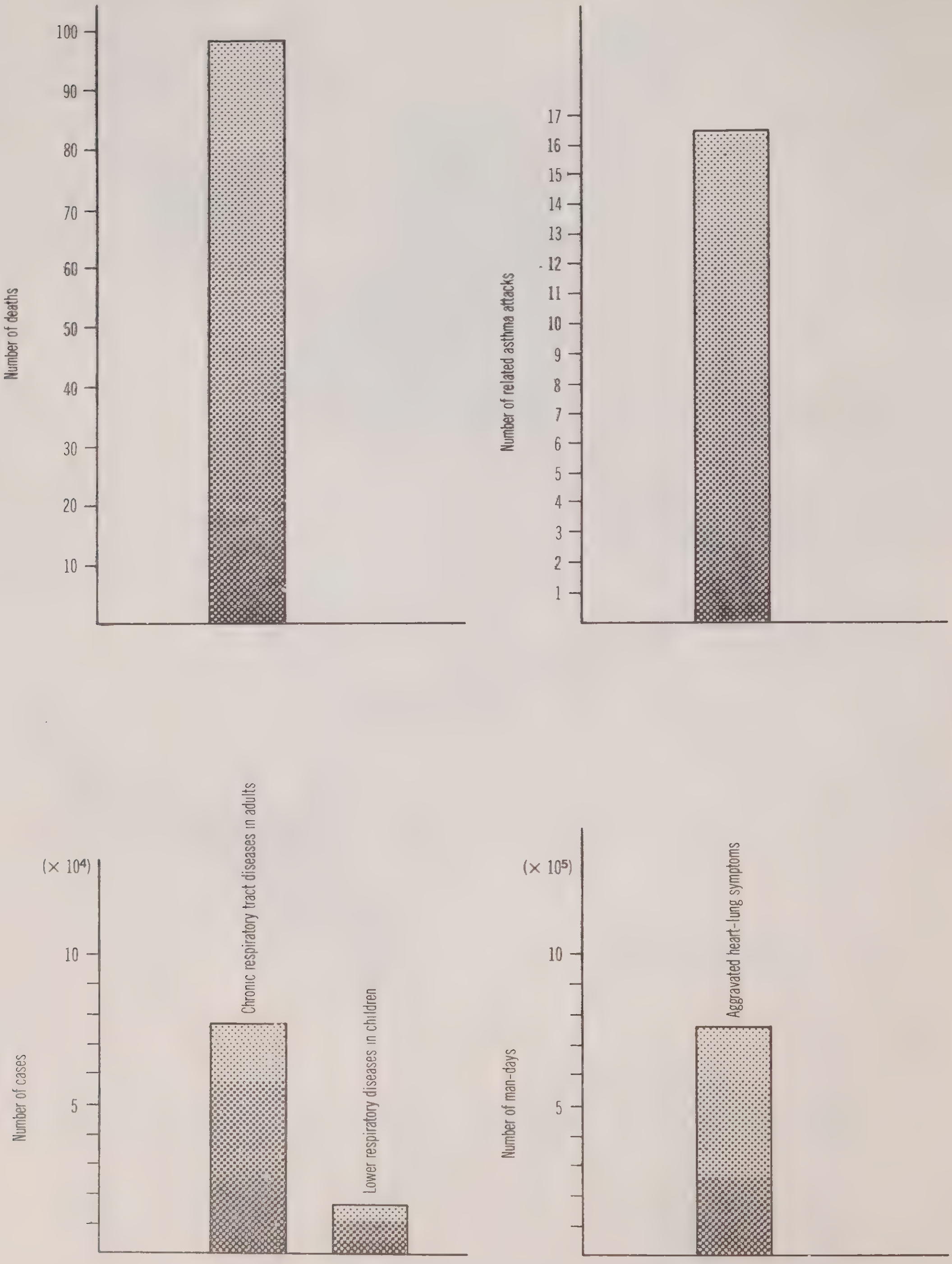
b) Text of this volume.

Figure 2.1 Terrain with Lakes Susceptible to Precipitation Acidity

Code	Total number of lakes	Mean area per lake (acres)	Percentage susceptible	Number of lakes susceptible	Total lake area susceptible (sq. mi.)
1	40,589	58.9	50%	20,295	1,868
2	76,728	98.0	20%	15,346	2,350
3	64,133	130.0	20%	12,827	2,605
Totals	181,450			48,468	6,823

Source: "Report on Acidic Precipitation", Ontario, Standing Resources Development Committee, June 1979.

Figure 2.2 Estimates of the Number of Fatal and Non-Fatal Illnesses Associated with Sulphur-Particulate Air Pollution from Coal-Fired Power Plants (Generating 3.091 Gigawatts of Electrical Net Output in One Year)



Note: Black areas of bars represent minimum values, variable shading represents uncertainties involved. Scale is adjusted as indicated in title.

Source: Based on "Unpaid Costs of Electrical Energy", by William Ramsay (U.S. estimates).

The Environmental and Health Impact of Oil- and Gas-Fired Electric Power Generation

Only 1.8 per cent of the electricity used in Ontario in 1978 came from oil-fired installations and only 2.2 per cent was generated from natural gas (see Table 1.1). The precipitous increase in the price of oil makes it very unlikely that the use of gas for the generation of electricity or, indeed, for other stationary applications will increase. It is likely to be limited progressively to applications, particularly in transportation, where the portability of the fuel is essential. Natural gas is too expensive a fuel to be used for relatively inefficient conversion processes such as electricity generation. However, it is a clean fuel and its relative abundance in Canada makes it attractive and economically feasible for installations that can use it at an efficiency exceeding, say, 75 per cent. This means that its use for the generation of electric power would be limited to co-generation plants.

The environmental and health impacts of burning oil in power plants are similar in nature to those for coal, described in Chapter 2. Only the quantitative and qualitative differences between coal and oil are dealt with below.

However, the extraction and transportation of oil and gas pose quite different hazards from the equivalent activities for coal. Like coal, not all these hazards occur within Ontario but they have implications on the environment and on health in other places and on the price of the fuels when they enter Ontario.

The Extraction of Oil

The environmental impact of oil production from wells occurs principally on land, from oil drilling, road location and construction, waste disposal, and accidental spills. Additional hazards occur if the drilling is in the Arctic, or in water, such as the Great Lakes. None of these hazards exists at present in Ontario. If at any time in the future significant discoveries of oil were exploited in Ontario it would almost certainly be for purposes other than electricity generation.

The extraction of oil from the bituminous sands of western Canada has a quite different impact on the environment. Some 3 to 5 tonnes of material have to be removed to recover one barrel of oil.[1] Reclamation of the land from which oil has been extracted in order to recreate arable or forested land is possible but requires a continuous, deliberate reclamation effort, not simply back-filling the excavated material. From an environmental point of view it is essential to plan the reclamation as an integral part of the mining operation.

Gas wells in Ontario are primarily restricted to offshore drilling rigs in Lake Erie. They have not had a significant impact on the aquatic environment[2] and present only a minor air-pollution problem.

Transportation of Oil and Natural Gas for Ontario

The Federal Department of Fisheries and Environment stated in its submission to the RCEPP:

> Transportation of oil and natural gas also may have serious environmental implications. The statistical risk of a spill from an oil tanker accident is substantially greater than that from a well blowout. As the transportation of oil out of the Arctic is not likely to take place for some years, there is some lead time available to develop improved technology and information and management systems, and also to develop and implement the necessary contingency plans. Toward this end, the Arctic Oil Ship Countermeasures Development Program is to be initiated by the federal government . . .
>
> The bulk transport of oil on the Great Lakes is also of environmental concern, particularly with the possibility of increased oil tanker traffic transporting foreign crude and possibly crude from Arctic and continental shelf sources. The potential for a major oil spill is always present. A spill could have serious consequences. The Great Lakes are the largest composite body of fresh water in the world and a source of water supply to approximately 30 million people. A major spill could have devastating effects on fisheries, wildlife, recreational areas, and water supplies.
>
> There has been significant progress in Canada's capability to prevent and deal with oil spills. However, the current state-of-the-art of oil spill clean-up cannot guarantee a satisfactory response to spills under many conditions, particularly those occurring in winter conditions or Arctic waters. The emphasis, therefore, must be prevention.
>
> Pipeline construction and operation through fragile arctic and semi-arctic ecosystems also poses

risks to the natural environment. Construction activities include the building and use of access roads and river crossings, and the mining of scarce granular materials for pipeline bedding, as well as the construction of the pipeline itself. These activities could cause considerable disruption to fish spawning activities, migration patterns, bird nesting areas, wildlife habitats, and the lifestyle of native people. An environmental concern with pipeline operation is the risk of a pipeline rupture, due to unstable foundations, faulty construction, or anti-social action. The spill from such a rupture could have serious effects on local aquatic or land-based ecosystems.[3]

One source[4] has estimated that the transportation oil spills associated with a 1,000 MW oil-fired power plant for one year amount to 1,500 barrels of oil, together with pipeline losses of an additional 540 barrels and miscellaneous discharges of a further 360 barrels. As these are calculated on a statistical basis, the probability of spills in Ontario depends upon the ratio of the transportation of oil within Ontario to that outside for the purpose of generating electricity. While the above amounts are not insignificant, the proportionate effect of the transportation of oil and gas required for the generation of electricity in Ontario now and in the future is likely to be very small compared with the effect of that transported for other purposes.

Generation

Table 3.1 compares the approximate quantities of gaseous effluents to be expected from coal-, oil-, and gas-fired power plants according to data in the Ontario Advisory Committee on Energy Report.[5] The data have been calculated on the basis of a 1 GW power plant operating at 75 per cent capacity in each case.

Table 3.1 Comparison of Gaseous Effluents from Fossil-Fuelled Power Plants[a]

	Coal	Oil	Natural gas
Consumption	2.18×10^6 tonnes	1.29×10^6 tonnes	2.25×10^9 m^3
Pollutant			
Sulphur dioxide	92,375	63,000	0.38
Nitrogen oxides	17,500	16,900	246
Particulates	–	1,290	9.5
Carbon monoxide	972	6	0.25
Aldehydes	4	161	1.9
Hydrocarbons	272	805	25.3
Other organic	–	–	2.5

Note a) Approximate quantities emitted (tonnes/year) by a 1,000 MW plant (75 per cent capacity factor)
Source: Based on Ontario, Advisory Committee on Energy. "Impact of Energy Use in the Environment in Ontario". Table VIII.

The effluents from an electric power plant fired with residual fuel oil are similar to those from a coal-fired plant except that the oil-fired plant naturally emits a much smaller quantity of particulates. The amount of sulphur dioxide emitted depends on the sulphur content of the oil but is of the same order as that emitted by a coal-fired plant.

The effluents from a gas-fired power station are much less. In particular, there is little in the way of particulates or sulphur dioxide. Nitrogen oxides constitute the principal effluent and even these are emitted in somewhat smaller quantities than from coal.

Health Impact of Oil- and Gas-Fired Fuel Cycles

The total health impact of each of the fuel cycles has been reviewed by several researchers. The resulting estimates of annual deaths and disabilities due to the entire fuel cycles of gas and oil are summarized in Appendix C. Representative data for each fuel are tabulated in Table 8.2 of Chapter 8 which provides a rough comparison of the health effects of the generation of electricity from gas and oil with those from coal and other fuel cycles.

Briefly, the estimated annual health impact of gas is about one-tenth that of coal as described in Chapter 2. The deaths and disabilities anticipated due to oil-fired systems lie between the values for coal and gas. In view of the fact that 10 times as much electricity is generated in Ontario from coal as from gas and oil together, it is evident that it would pay to concentrate any available resources on cleaning up the coal-fired fuel cycle.

CHAPTER FOUR

The Environmental and Health Impact of Nuclear Electric Power Generation

Thirty per cent of the electric energy used in Ontario in 1978 was furnished by nuclear generating plants. The largest operating nuclear power station (2,000 MW) is Pickering A, a few miles east of Toronto.

Ontario uses the CANDU reactor, which originated in the AECL's Chalk River Laboratories and was developed by the AECL group at Sheridan Park, near Toronto. It differs from the light-water reactors (LWR) that are used elsewhere, particularly in the United States. CANDU uses "heavy water" as a moderator and coolant and natural uranium as its fuel, whereas LWRs use ordinary water but require the uranium to be processed to enrich it by increasing the proportion of the fissile component uranium-235 from the naturally occurring level of 0.7 per cent to about 3 per cent.

While CANDU and LWR reactors have important differences, their impacts on the environment are similar in many respects. The similarity enables us to use data from some of the very detailed studies of reactor safety and reactor emission studies that have been conducted in the United States. Unfortunately, no studies in similar detail have yet been conducted on Canadian installations.

While the use of U.S. data is less than ideal, it does serve to set the probable broad limits of the risks inherent in the normal operation of nuclear power plants. However, care is taken to highlight instances in which the U.S. data are not at least approximately applicable to CANDU.

As in the case of coal- and oil-fired generating stations, nuclear stations involve hazards associated not only with the generating plant but with all stages of the fuel cycle including mining, fabricating, and transporting the fuel and the eventual disposal of mine tailings and used fuel. Two major differences should be borne in mind. The first is that the quantities of fuel, solid wastes, and effluents associated with a nuclear power plant are at least 10,000 times smaller than those for an equivalent coal-fired plant; the second is that wastes associated with the nuclear plant are highly radioactive and have to be handled with the care appropriate to the intensity and nature of the emitted radiation. The radioactivity is very long-lived, which poses the problem of disposing of it in such a way as to produce a negligible increase in the radiation to which the public is exposed, not only now but for centuries to come. Details of the units used in the measurement of radiation and its effects are given in Appendix E.

In the case of coal much of the impact is due to the sheer bulk of coal that must be handled and transported and to the waste material that must be disposed of. In the case of nuclear power, the amount of fuel and waste material associated with the power plant is comparatively small. The problems caused by reactor waste are due to its long-term intense radioactivity, not to its bulk. On the other hand, the amount of waste from the uranium mining and milling process is comparable to the amount produced by the burning of coal. This fact, combined with the radioactive nature of most of the waste, poses certain problems, which are discussed below.

Uranium Mining, Milling, and Fuel Fabrication

Occupational Hazards

The nuclear power plants in Ontario required some 400-500 tonnes of uranium for the fabrication of fuel to generate 3.3 GW·years of electric energy in 1978. Most of the uranium-mining in Ontario takes place in an area of about 100 km^2 to the north of Elliot Lake and most of the uranium ore mined is processed for export. The Ontario Hydro requirements are only a fraction of the output of the Ontario mines, with a capacity of 16,000 tonnes per day of mill feed, which corresponds to about 4,000 tonnes of uranium a year. Moreover, the mines are undergoing an expansion programme to increase the potential feed to the mills to more than 36,000 tonnes per day by the mid 1980s.

The yield of uranium from uranium ore varies with the quality of the ore and the process, but a useful rule of thumb, which is accurate to within a factor 2 either way, is that 1 tonne of ore yields 1 kg of uranium. On a larger scale, this means that 1,000 tonnes of ore yield roughly 1 tonne of uranium. The waste (known as "tailings") weighs practically as much as the original ore and occupies up to twice the volume.

In the course of mining several thousand tonnes of uranium ore a day the miners inevitably breathe in some of the radioactive gases that are continuously emitted by the ore and some of the fine dust (airborne particulates) that is generated by the mining operation. The health and safety of workers in uranium mines has been the subject of several studies, including that of the Royal Commission on Health and Safety of Workers in Mines (the Ham Commission), which published its report in 1976.

The radon gas that comes from the ore emits alpha particles that are the least penetrating kind of radiation. The radon decays with a half-life of about four days. In other words, the radiation is halved in four days, halved again in the next four, and so on. The products of radon decay are the so-called radon daughters, the isotopes polonium-218, lead-214, bismuth-214, and polonium-214. Some of these daughters, if inhaled into the lungs, can cause cancer. Regarding these radon decay products, the submission to the RCEPP by Fisheries and Environment Canada observed:

> Recent evidence has indicated that the risk of lung cancer increases with exposure, and that it is not possible to define a threshold of exposure below which the risk is zero. Although the regulatory exposure limit has been lowered in recent years, there is a need to increase studies on the health-related aspects of uranium mining.[1]

Studies of the incidence of cancer in uranium workers have led to the adoption in the last few years of much stricter standards to limit the radiation exposure of uranium miners.

Ramsay[2] sees the main possibility for further improvements as a reduction in the working hours of uranium-miners or the adoption of expensive closed-cycle breathing systems, and he implies that a further reduction of standards is impractical. However, the recent *Report of the Environmental Assessment Board on the Expansion of the Uranium Mines in the Elliot Lake Area*[3], while supporting the present criteria, mentions some disagreement between expert witnesses as to their adequacy.

A similar hazard exists for the workers in the mills in which the ore is crushed and the uranium oxides extracted in the form of "yellow-cake" (U_3O_8), which is used in the manufacture of fuel rods. There is speculation[4] that the inhalation by mill-workers of dust from uranium and from thorium-230 (a decay product of uranium) might eventually cause cancers of the lymphatic system.

Since most of the long-lived radioactive elements associated with uranium are left in the tailings at the mine site, and in view of the much smaller quantities of material that are handled in the fuel-fabrication process, the risk to workers in fuel fabrication is likely to be less than that in the mining and milling process.

Ramsay[5] quotes data that estimate 0.1 to 0.3 deaths from occupational accidents per 1,000 megawatt years of plant operation and 0.1 to 0.2 deaths from radiation-induced diseases. Others[6] quote similar data for fatalities and about 2 to 10 cases of occupational disability due to injury or disease in mining the fuel needed to operate a 1,000 MW plant for one year (75 per cent capacity factor). These data are summarized in Appendix A and compared in Chapter 8 with those for the extraction of fossil fuel.

Impact on the Environment and on Public Health

The mining process itself presents little if any hazard to the public. The major environmental and public health impact is that of the mill tailings, which are dumped at selected sites close to the operations. The tailings, which have approximately the same weight as the original ore and usually a somewhat greater volume, contain radioactive substances, principally radium-226 and acids that are leached into the water system unless stringent precautions are taken. At present there are some 85 million tonnes of tailings in the Elliot Lake region and the consequent contamination of the Serpent River basin has been a matter of great concern and considerable study. With the projected expansion of the uranium mines in that area[7] to a potential throughput of 30,000 tonnes a day, seven days a week, the amount of tailings could be doubled during the 1980s.

The management of the tailings in the short- and long-term is extremely important. The tailings are piped to selected tailings areas as a slurry. The point of effluence of the slurry is moved as necessary to distribute the tailings over the disposal area. Tailings can be stacked above ground and allowed to dry, stacked and flooded, or disposed of under water in a lake. All methods have been used and each has its advantages and drawbacks.

The principal contaminants are acid that is generated in the tailings and radium-226. As mill water is normally used in the slurry, the presence of large quantities of ammonia presents a further problem. Moreover, a fraction of the radium-226 continuously decays into its daughter radon gas, which is found in significant concentrations in the tailings areas.

Maintenance of the tailings in the wet state reduces the generation of dust and deprives the acid-producing chemical process of oxygen. It also reduces radon emanations. However, it requires a larger surface area because stacking and coning are not possible, as described below.

The tailings are deposited where possible in natural basins. Dams are constructed where the bedrock is not of sufficient height. The permeability of dams is a matter for concern and plastic (hypalon) liners are used where there is a risk of excessive leakage to the surrounding area. In order to reduce the quantity of radioactive materials, in the tailings, most of the radium is precipitated by the addition of barium chloride to the leachate. The resulting "active residue" is deposited in settling ponds that are separate from the tailings ponds. The question of the ultimate disposal of these active residues has not been solved. They may constitute a hazard for centuries, if the conditions are such that radium is leached out by ground-water circulation.

In order to minimize the land area that must be given over to tailings, several experiments are under way. The mechanical stability of high stacks or wide-angled conical heaps is under study by Denison Mines. Two other techniques for the disposal of tailings have been endorsed by the Environmental Assessment Board.[8] The first is to return as great a quantity of tailings as possible to the mines from which the ore came – a process known as back-filling. While back-filling may sound particularly attractive, it can only cope with part of the problem because the tailings may have as much as twice the volume of the original ore. Moreover, back-filling poses significant occupational health problems as well as operational problems. In spite of these problems, it may well prove possible to dispose of some part of the mill tailings in mined-out holdings. The second technique recommended by the Environmental Assessment Board is to cover the tailings areas with sand and soil and to plant vegetation on them. This is said to cause most of the water to run off, rather than penetrate the tailings, and thus reduce the rate at which chemicals and radioactive elements are leached from them into the ground water.

Accidental spills of tailings slurry have occurred where a slurry pipeline runs across an area that is not designated for tailings disposal. The Environmental Assessment Board[9] recommends a new evaluation of tailings lines, pumps, and valves with a view to preventing excessive discharge of pollutants into the environment, which might result from the failure of these components.

Fig. 4.1: p. 43

Figure 4.1 is a map of the Elliot Lake region showing the mines, mills, and tailings areas. It may be seen that there are several square kilometres of tailings areas. Furthermore, the need for stringent precautions to minimize the risk of pollution to the lake and river system is clearly evident.

Water Pollution

The agreed water-quality objectives for the Serpent River watershed are:[10]

- pH – 6.0 or above
- Ammonia – 1.0 milligrams per litre or below
- Dissolved radium-226 – 3.0 picocuries per litre or below
- Total dissolved solids – 500 milligrams per litre or below

There are no guidelines for nitrates or heavy metals.

The pH value is specified because of the need for a certain level to maintain aquatic life. To obtain self-sustaining species of high-quality fish such as trout, a pH of 6.5 or above is said to be necessary. However, the presence of both leached acids and ammonia means that the nominal pH level is not the only criterion to be met. If the pH is raised by reducing leached acids in the presence of ammonia, then some ammonia shifts to a toxic form as the pH level rises above 6.0. Consequently, to raise the pH value to 7.0, say, it would be necessary to reduce the levels of both acid and ammonia in order to achieve the desired balance.

Table 4.1 is a summary from the Environmental Assessment Board's report[11] of the mean values of measurements made on water in the Serpent River system. Broadly speaking, the eastern arm and central arm of the system are no longer suitable for fish or swimming. The western arm is still in reasonably good condition. The Environmental Assessment Board has endorsed the objective of restoring the aquatic habitat in the Serpent River.

Table 4.1 Serpent River System Water Quality Measurements[a]

	pH	Dissolved radium (pCi/L)	Ammonia (mg/L-N)	Nitrates (mg/L)	Total dissolved solids (mg/L)
Eastern Arm					
Dunlop Lake (outlet)	7.5	1.0	0.07	0.15	27
Quirke Lake (eastern end)	5.3	5.0	2.38	6.45	239
Wiskey Lake	5.4	6.0	1.3	3.58	172
Pecors Lake (outlet)	5.2	7.0	0.96	3.67	147
Central Arm					
Crotch Lake (outlet)	6.2	–	0.102	0.144	276
McCabe Lake[b]	7.3	7[c]	0.066	0.308	136
May Lake (southern end)[b]	3.7	12[c]	0.360	0.244	182
Hough Lake[b]	4.4	14[c]	0.241	0.235	125
Western Arm					
Elliot Lake	6.8	1.0	0.40	0.20	68
Depot Lake	7.0	1.0	0.052	0.156	82
McCarthy Lake[b] (southern end)	6.5	3[c]	0.411	2.06	116
Esten Lake[b]	6.7	1[c]	0.06	0.34	85
Serpent River					
McCarthy Lake (outlet)	6.4	5.5	0.39	1.95	111
Serpent River (at Hwy. 17)	6.7	3.9	0.246	1.47	96

Sources:
a) Government of Ontario, Environmental Assessment Board, the expansion of the Uranium Mines in the Elliot Lake Area, Final Report, 1979.
b) Data from RCEPP Exhibit 278, Ministry of the Environment, 1978.
c) Data from RCEPP Exhibit 366, Ministry of the Environment, Radiological Survey, 1978.

The level of radium that is tolerable in the water system is more a matter of public health than environmental concern. At present, the federal standard (10 picocuries per litre) differs from the provincial standard which is 3 picocuries per litre. Table 4.1 shows that the level in most places that were tested lies between these two values. The setting of new, consistent standards is under review.

Air Pollution

Provincial air-quality standards and criteria are discussed in Chapter 9 of this volume. Sample measurements of actual air quality have shown[12] that the levels are rarely exceeded even in the vicinity of the mining operations. Radon concentrations drop off rapidly as the distance from the tailings increases and are only a problem where tailings have been used as land fill on construction sites or for other purposes outside the tailings areas. Such practices have been discontinued.

Future Prospects

Attempts have been made and are being pursued to develop air- and water-quality models as tools for use in the prediction of future impacts of mill tailings in respect of both the amount and the disposition of the tailings. Such models are controversial and are often able to represent only particular, extreme cases. Nevertheless, provided they are used to supplement, not replace, a continuous monitoring programme, they may provide useful guidelines for future operations and standards.

However, many feel that there must be a better way of disposing of tailings than dumping them in tailings ponds, the long-term consequences of this practice being still in doubt. The tailings contain valuable minerals that might under some circumstances be worth extracting. An argument could be made for a major research project on the use and disposal of tailings, perhaps sponsored by the federal government and conducted by the research organizations of interested provinces, including Ontario and Saskatchewan. These organizations already have a good deal of experience that is relevant to the tailings problem.

It should be re-emphasized that the disposal of tailings is the only problem associated with nuclear power that involves the handling of very large quantities of material. That is why it is so difficult. The other major problem – the disposal of radioactive waste – may be easier to face, in spite of the high radiation levels, because for every tonne of tailings there is only about a kilogram of spent fuel. The storage space necessary for spent fuel is thus only one-thousandth of that required for tailings.

The Impact of Heavy Water Production

Unlike nuclear power plants in many other countries, the Canadian system uses large quantities of heavy water (D_20) as both moderator and coolant. Ordinary water contains a very small percentage of heavy water in which the hydrogen atoms are replaced by "heavy" hydrogen, or deuterium. A two-stage chemical process is used to increase the concentration of D_20, first to about 20 per cent, then to 99.8 per cent. The first stage uses large quantities of hydrogen sulphide gas (H_2S) as the intermediary for the exchange of hydrogen for deuterium. While the hydrogen sulphide is normally recycled, there are losses during the purging of the enriching unit, during maintenance, and when the enrichment cycle is upset for any reason. There is also a remote possibility of the need for emergency venting of very large quantities of H_2S (e.g., up to 400,000 kg per hour[13]). For these reasons, provision is made for the safe combustion of released H_2S in a flare stack and the subsequent dispersion of the resulting sulphur dioxide into the atmosphere. Nevertheless, quantities of H_2S giving ground concentrations greater than the Ontario Ambient Air Criterion of 0.25 ppm for one hour have been released, but with diminishing frequency as experience has been gained. In one of its submissions to the RCEPP, Ontario Hydro stated:

> As a result of commissioning and experience with Bruce HWP A in 1973, Ontario Hydro has gained experience in the design, operating and maintenance measures necessary to ensure performance acceptable to regulatory authorities and to the surrounding communities.[14]

The catastrophic failure of a critical piece of equipment (e.g., the rupture of a storage vessel) could release hundreds of thousands of kilograms of H_2S to the atmosphere in a very short time. Unlike emergency venting, the procedure in this case would be not to route the gas through the flare stack. Such an accident could be a threat to human life as far as 20 km from the plant. While the probability of such a catastrophe is low, contingency plans have been made.

The discharge of H_2S constitutes a potentially serious problem. Not much is known about the effects of long-term exposure to low concentrations or about what constitutes a lethal concentration. The Atomic Energy Control Board is responsible for setting standards and for monitoring the performance of heavy-water plants against them.

The Health and Environmental Impact of a Nuclear Generating Plant

It is generally agreed that the normal operation of a nuclear power plant has a smaller impact on the health of workers and the public, and does less damage to the environment, than other activities related to the nuclear fuel cycle, namely, mining and processing and the disposal of wastes.

The public distrust of nuclear power, insofar as it exists, is based rather on a fear of accidental releases of radiation due to mechanical or human error, as exemplified by the recent events at Three Mile Island in the U.S. The extreme example of such an accident would be a reactor core melt-down. It will be seen that opinions vary widely on the probability of such an event because the history of nuclear power is too short to provide an adequate statistical basis for firm predictions. It is important, therefore, to separate the impact of surprise-free, normal operation and maintenance from that of accidental failure, whether of human or mechanical origin.

Occupational Hazards in Nuclear Generating Plants

The working environment for plant employees is carefully controlled. Highly specialized instruments are used to monitor radiation both in generating stations and outside them. For example, "gamma-fields" are detected by means of single crystal scintillation counters and pulse-height analysers. Neutron radiation is measured by the activation of manganese foil, and beta-radiation is measured by conventional Geiger-counter techniques. The Radiation Protection Bureau of Health and Welfare Canada provides a film badge detection service for all workers entering radiological zones in all nuclear generating stations. The film badges are worn for a period of two weeks and are subsequently processed in Ottawa. The film indicates whole-body exposure, and measures dose equivalent directly in rems. (The rem is defined in Appendix E.) The whole-body dose is normally due to gamma-radiation. Because the film badge is only capable of measuring gamma-radiation exposures, an attempt is also made to obtain a measure of skin dosages of beta-radiation, but, insofar as plant personnel are concerned, the external gamma-radiation exposure is normally the factor that determines the time an individual worker is allowed to spend in a particular work area.

A computer programme known as the "dose control programme" has been developed at Pickering to

handle all data obtained from the gamma- and beta-radiation monitors. At the end of every two-week monitoring period, reports are obtained that give the up-to-date totals for both the external and internal doses received by each worker. These are used to determine the further exposure each worker may receive, and, at the end of each quarter, the dose data are transferred from the computer files to long-term dose-record files for all employees at the generating station.

By these means the exposure of each nuclear worker is kept within the 5 rem per year dose limit specified in AECB regulations. Views on the adequacy of this and other standards vary, but there is increasing pressure to reduce the dose limit by as much as a factor of 10 until more is known about the effects of very low radioactive levels.

Exposure of Workers during Major Reactor Maintenance

The time comes when, due to radiation damage or premature failure, certain reactor components must be replaced. This involves work in areas in which the annual maximum radiation dose of 5 rem can be acquired in a very short time, e.g., a day or two. Plant workers who are not normally exposed to high levels of radiation are used, and temporary workers are hired for a training period and for the time it will take them to absorb the maximum dose while performing the specialized task for which they have been trained. Such workers have been referred to in the press as "sponges", and questions have been raised about the practice on the basis that not enough is known about the effects of short-term exposures of this kind on the ultimate health of a worker.

As nuclear plants age, the need for replacement of reactor components will have to be faced. For example, it is now known that the entire core of pressure tubes of each CANDU reactor at Pickering and Bruce A will have to be replaced due to "stretching" – those at Pickering probably in the mid 1980s. The selection, training, and use of a large number of temporary workers for purposes such as this may pose as much of a social problem as an organizational one.

Impact of Nuclear Generating Stations on the Environment and Public Health

Controlled amounts of radioactive effluent are released to the environment through ventilation discharge points and through the condenser discharge water of a nuclear power plant. Under normal circumstances the radiation level even at the perimeter of the plant area is very small, whether as a percentage of the level permitted by AECB regulations or in terms of its contribution to the background radiation from natural sources.

A derived release limit is specified (see Appendix B) for each category of radioactive material that is released. Tables 4.2 and 4.3 show the levels from Pickering as a percentage of the derived release limit.

Table 4.2 Gaseous and Particulate Effluents from Pickering A, 1974

Category	DRL[a]	Release as average percentage of DRL
Tritium	2.2×10^5 Ci/week	0.22
Noble gases	4.3×10^4 Ci-Mev[b]/week	0.20
Iodine	0.4 Ci/week	0.02
Suspended particulates	1 Ci/week	0.07

Notes:
a) Derived release limited (AECB-approved).
b) Million electron volts.

Table 4.3 Liquid Effluents from Pickering A in 1974

Category	DRL[a]	Release as average percentage of DRL
Tritium	1.65×10^7 Ci/year	0.09
Other radioactivities	900 Ci/year	0.28

Note a) Derived release limit (AECB-approved).
Source: A.M. Aiken, J.M. Harrison, and F.K. Hare. "The Management of Canada's Nuclear Wastes." Ottawa: Department of Energy, Mines and Resources, August 1977, p. 22.

The major radioactive pollutant from a CANDU reactor in normal operation is seen to be tritium. The tritium atom is a hydrogen atom with two additional neutrons in the nucleus. The tritium is produced by neutron bombardment of the heavy-water moderator. It has a half-life of 12.5 years and may represent a potential long-term hazard due to buildup as nuclear power stations proliferate.

The tritium is discharged as tritiated water to both the atmosphere and the cooling water. The submission to the RCEPP by Fisheries and Environment Canada stated:

> The quantity of tritium released annually from a typical CANDU nuclear generating station is about 40,000 curies compared to a total of 2 to 3 curies of other long-lived fission products. Two-thirds of this tritiated water is released to the atmosphere, where it rapidly exchanges with atmospheric moisture and precipitates in the neighbourhood of the source, contaminating the surface waters, soils, and vegetation. The remainder of the tritiated water discharged from the station is diluted by the condenser cooling water and dispersed into the lake. An estimate of the build-up of tritium in the Great Lakes from Ontario Hydro's future nuclear operations predicts Lake Ontario tritium levels to increase from the current 400 picocuries per litre to about 2,000 picocuries per litre by the year 2000. Even though the radiological dose to an individual drinking the water will only increase by 0.3 millirem, this will be a major increase in concentration. In addition, stagnant pools of tritium could collect near discharge areas on a calm day (such pools have been observed off Pickering) and be carried by lake current to public water supply intakes, thus inflicting a higher, short-term dose on the public.
>
> Tritium releases will be involved in the transboundary movement of pollutants from Canadian and U.S. waters. As U.S. reactor systems discharge only minor quantities of tritium, their effect on lake tritium levels will be negligible, so that a future concern may develop in the U.S.A. over pollution of U.S. waters by Canadian nuclear generating stations.[15]

The discharge of cooling water from Pickering and other (including U.S.) nuclear generating stations into the Great Lakes system gradually increases the levels of long-lived radionuclides in the lakes. A dose level of 1 millirem per year has been selected as the basis of U.S–Canada agreement on a radioactive water-quality objective.

Iodine-131 is a fission product that is released only when a defect occurs in a fuel bundle. However minor defects have occurred and small quantities of iodine-131 have been released on occasion from CANDU reactors. They are said[16] to have been well below the limits shown in Table 4.2.

The potential danger of iodine-131 is that it concentrates in the thyroid gland and may, after a period cause thyroid cancer. As a normal route for iodine would be through contaminated milk, it constitutes a particular threat to children. Emission of radioactive iodine would be one of the more serious consequences of reactor accidents.

The other main category of effluent (Table 4.2) is that of noble gases, which include isotopes of argon, krypton, and xenon.

The CANDU reactors are equipped with charcoal beds designed to keep the quantities of radioactive noble gases (argon, krypton, and xenon) released to the atmosphere below the specified derived release limit. The system is also designed to recover heavy water and deuterium gas from the effluents, and this automatically reduces the tritium release.

A report on the management of Canada's nuclear wastes by the Department of Energy, Mines and Resources commented:

> It is these gaseous releases that have been accused on occasion of causing increases in infant mortality near nuclear power plants, of causing cancers, or of shortening the life span of nearby residents. We find no evidence to support these claims. Furthermore, radiation biological research indicates that they cannot be correct. It is interesting to note that there is often more airborne radioactivity put out by a coal-fired plant than from a nuclear one of equivalent electrical power output, because of the release of the naturally occurring radioactive materials from the coal.[17]

In summary, all the evidence on nuclear power stations in Canada and elsewhere shows that it is quite feasible to maintain radioactive emissions from the power plant at levels that are essentially harmless to the environment and public health in the short term and the long term provided that all control procedures are followed and all systems are operating normally. It is only during departures from this ideal state due to human error or technical fault that the amounts of radiation released would expose the public to a measurable increase in risk. The exception is the buildup of tritium in the Great Lakes which has been referred to above as a source of concern.

Nuclear Reactor Accidents

The distrust of nuclear power stems very largely from a fear of major accidents involving nuclear reactors. While polls in the United States once indicated[18] that the majority of the U.S. public regarded nuclear power as safe, there is an increasingly strong and vocal opposition to nuclear power in the U.S. and in most other countries that have introduced it.

Any meaningful prediction of the contribution of nuclear accidents to the health and environmental impact of nuclear power generation depends on several things. The first is the specification in detail of all the types of accident that might occur. The second is an accurate determination of the nature and amount of radioactive matter that would be released by each type of accident. The third is an estimate of the numerical probability (e.g., one chance in a million per annum) of specified types of accident.

Types of Nuclear Accidents. The fact that several incidents involving the failure of reactor safety systems have taken place suggests that the release of significant quantities of radioactive pollutants from this cause cannot be ruled out. In 1957, there was a fire in a plutonium-production reactor at Windscale, from which one of the effects was the contamination of milk with radioactive iodine over a wide area of northern England. Few details are available of an incident that is known to have occurred in the Soviet Union and is believed to have contaminated a wide area.

There have been three nuclear accidents in the United States since 1975: a fire in a control cable at Brown's Ferry, Alabama (1975); electrical control failures at Rancho Seco, California (1977); and the recent, serious breakdown of mechanical systems and human control at Three Mile Island, Pennsylvania (1979). None of these incidents involved catastrophic failure of the reactor to the extent that containment of radioactivity was seriously breached, although the latest incident came very close.

The Environmental Effects of Nuclear Accidents. Once the containment is breached a large amount of radioactive material will be emitted into the atmosphere. It will eventually be deposited on the ground. The location and extent of the contaminated area will depend on the weather. If there is little wind, or if it is raining, there will be heavy contamination within a few miles of the site. If it is dry and windy, the contamination may extend for hundreds of miles. The principal contaminants include the radioiodines, alkaline earths, heavy metals, and other fission products. These reach the human body by respiration while they are still airborne. Once they have been deposited on the ground they contaminate crops and vegetation. They also seep into ground water. Therefore, they reach man through air, food, and water

A recent Massachusetts Institute of Technology study[19] (based, of course, on U.S. reactors) suggests that an area of about 10 square miles would be contaminated to life-threatening levels in stable, wet weather. The report stated: "In such an area, people not evacuated within 24 hours are likely to suffer radiation doses of 300-500 rads, sufficient to cause the death of as much as half of the exposed population. Given the typical suburban population density of the northeastern United States – of the order of 500 people per square mile – 24-hour exposure would result in several thousand short-term fatalities."

Weather conditions and the wind direction would affect the number and distribution of casualties Special topographic features such as mountains and valleys can modify the air flow and change the pattern of contamination. Consequently, the risk of accident is likely to be a major factor in the siting of nuclear power plants in the future. Siting in remote areas involves a trade-off between environmental hazards and transmission costs; rural populations are naturally opposed to this though it would reduce the hazards to heavily populated areas, where the radiation would be too low to produce short-term effects but possibly high enough to cause a significant increase in the incidence of cancer in the longer term.

The Probability of Nuclear Accidents. The history of nuclear power is so short and the number of accidents so small that the statistical data accumulated to date are quite inadequate as a basis for prediction, and will continue to be for many years to come, if accidents are as rare as experts expect Consequently, current estimates of the probability of nuclear reactor accidents are essentially theoretical, based on the composite estimated probabilities of the breakdown of various systems and components. As in all such cases, any estimate is strongly contested; experts differ and the subject becomes extremely controversial. The emotional reaction of "nukes" and "anti-nukes" to the subject adds fuel to the fire of controversy.

In fact, a very great deal of serious work has been done in an attempt to estimate the probability of reactor accidents and their consequences, much of it in and stemming from the Rasmussen report[20] which relates to light-water and boiling-water reactors in the U.S. and not specifically to CANDU reactors. No such detailed study has been carried out in Canada. However, some believe that the U.S.

estimates, if valid, tend to exaggerate the risk relative to CANDU, which confines the fuel in individual pressure tubes rather than in one large pressure vessel as in the U.S. reactors. However, recent testimony before the Ontario Select Committee on Hydro Affairs leaves the matter in doubt, in the absence of a detailed study of the safety of CANDU.

The following note on the Rasmussen report is quoted from "Unpaid Costs of Electrical Energy" by Ramsay[21]:

> The Reactor Safety Study calculated the probability that (1) a nuclear reactor accident would occur with a significant release of radioactivity, and (2) the radioactivity would be carried to locations where it could expose a population to possible health risks.
>
> All possible components in the plant that might break down so as to eventually lead to such an accident were examined. For example, one possible way for an accident to occur would be for a large pipe to break, then for both the emergency core cooling system and the containment spray system to fail, and then for the containment itself to be breached, releasing radioactivity into the atmosphere One must calculate the probability for this total sequence of events, and for all the different possible events – including human errors – that could lead to a core meltdown or other serious accident, such as the bursting of the reactor vessel.
>
> This type of probability calculation was carried out for two typical existing reactors. Normal uncertainties in the design and the failure rates of components were also taken into account in order to reflect differing conditions in 100 typical reactors.
>
> If the radioactive material gets outside the reactor, then its destructiveness depends on whether the wind is blowing in the direction where people live, whether there is rain, and how many people live in the affected area. The chance of 90 different kinds of weather conditions occurring at each of six representative sites was then calculated, taking into account local populations.
>
> For example, the probabilities for a worst-case accident could be calculated as follows: (1) The probability of an accident occurring in each reactor in which a substantial amount of radioactivity would be released was 5 in 1 million; (2) the probability of the weather being unfavourable and exposing a large population to the radioactivity was 1 in 1,000; (3) the chance of a worst-case accident happening was then 5 out of 1 billion for each reactor-year; (4) the number of latent cancers inflicted on such a large population from such an amount of radiation would be 48,000; and (5) this can be interpreted to mean that we "expect" only 0.0002 fatalities per reactor-year from this worst-case accident.

It should be noted that the latent cancers referred to include world-wide effects over all time and represent a minute increase in the incidence of cancer from all causes.

The data contained in the Rasmussen report[22], which is the only detailed work on the risks of nuclear accident, have been quoted by many workers in the field and subjected to varying degrees of criticism Ramsay[23], after a study of some of the criticisms of Rasmussen's report, accepts his data "as modified

Fig. 4.2: p. 44

by modest error limits". Figure 4.2 shows estimates of fatalities and some illnesses that may be expected each year as a result of nuclear power accidents. These are, of course, based on U.S.-type reactors but have been pro-rated to the annual electric energy production of Ontario plants in 1978.

Table C.5 in Appendix C includes data from several published sources, all of which depend on the Rasmussen report or interpretations of it. However, a report[24] to the U.S. Nuclear Regulatory Commission by a Risk Assessment Review group, chaired by H.W Lewis, while concentrating on a detailed critique of the methodology and assumptions of the Rasmussen report, concludes that the actual uncertainties are much greater than Rasmussen's figures indicate.

A very recent paper by J.P. Holdren et al.[25] supports that view and, in suggesting "partial corrections" of an earlier paper by Herbert Inhaber[26] increases the upper limit of the public risk by a factor of about 50.

Table 4.4 is a summary from Holdren's paper of various upper-limit risk estimates for nuclear accidents. With regard to the wide range of uncertainty, Holdren wrote

> We must emphasize that it is not our contention that the higher figures in the above table are the "right" ones. Our point is rather that there is an enormous range of legitimate uncertainty about the appropriate value to use for expected casualties from reactor accidents.[27]

Table 4.4 "Upper Limit" Risk Estimates for Nuclear Accidents

All figures are expected deaths per million megawatt years (assuming reactor size of 1,000 MW and load factor of 0.70 per cent)
Comar and Sagan, catastrophic accidents only: 1.6
Smith, Weyant, and Holdren, routine operation only: 13
Rasmussen report (final), central estimate for all accidents: 33
Comar and Sagan, sum of routine operation and all accidents: 230
AECB-1119, sum of routine operation and all accidents: 230
Rasmussen report (final), upper limit for all accidents: 490
Smith, Weyant, and Holdren, upper limit for all accidents: 10,000
Ford/MITRE, upper limit for all accidents: 50,000–100,000

Source: Holdren et al., "Risk of Renewable Energy Resources; A Critique of the Inhaber Report" Energy and Resources Group, University of California June 1979, p.124.

The accident at Three Mile Island raises doubts as to whether a mathematical study such as the Rasmussen report can take into account a combination of mechanical failure and human error on the scale that was demonstrated in that accident.[28] While nuclear power stations have a variety of safety systems designed to prevent abnormal events (including melt-down) and to keep radioactive gases from escaping in the unlikely event of a melt-down, the unexpected can happen. The balance between the provision of safety measures and the economic operation of the station means that a judgement is inevitably made as to how nearly the safety measures can approach perfection without destroying the viability of the operation. A similar judgement is made in the design of a jet aircraft. However, the jet is operated by a highly-paid expert who is trained to react quickly to the unexpected (and rare) emergency. Even so, the long periods of normal emergency-free operation must make it difficult to maintain a high level of alertness at all times. The problem is much more acute at a nuclear power station, which operates for 24 hours a day and in which the monotony is not relieved by take-offs and landings. Moreover, unlike the jet cockpit, the power station control centre is not always manned by a highly paid expert executive.

A report that reviewed the human factors in power-plant design, operation, and safety was prepared for the RCEPP.[29] It emphasized the importance of the selection and training of operators and the evaluation of their ability to cope with the conflicting demands of their job. It also urged that more attention be paid to the design of the man-machine interface. Because these considerations are of such importance to the assessment of the risks of nuclear power and contribute so much to the uncertainties this report should be read by anyone concerned with the subject.

There is an urgent need for further studies on ways to reduce the probability and the consequences of human error in the operation of nuclear power stations, as well as for studies similar to the Rasmussen work on the probabilities and consequences of technical failures in reactor operation.

The Disposal of Nuclear Wastes

It was pointed out at the beginning of this chapter that, apart from mine and mill tailings, the amount of waste from the nuclear power cycle is very small compared with that from fossil fuels However while the hazards from fossil-fuel wastes are mainly due to chemical pollutants, the wastes from a nuclear reactor emit dangerous levels of radioactivity that must be prevented from contaminating man's environment in the short and long term. This means either dispersing the waste harmlessly into the environment, which is achieved with gaseous and liquid wastes, or converting it into a form in which it can be stored, undamaged, until the radioactivity decays to a safe level – which is necessary for all highly radioactive solid wastes.

Apart from contaminated protective clothing and filters used in ion exchange resins, the principal source of solid waste is the spent fuel bundles that are removed from the reactors once their efficiency declines. These and other miscellaneous wastes amount to a total annual volume of about 1,250 m^3 from a station such as Pickering A. Table 4.5 shows the breakdown of these solid wastes.

Table 4.5 Impact of 1,000 MW Nuclear Power Station for One Year of Operation (75 per cent capacity factor) (Tailings, Wastes, Emissions)

Activity	Impact	Amount	Unit	DRL
Mining[a]	Land disturbed	45,000	m^2	
	Tailings	79,000	tonne	
Generation including disposal[a]	Fuel consumed	130	tonne	
	Cooling water (one-time)	3×10^6	L/minute	
	Thermal discharge	1,600	MW·y	
	Solid radioactive wastes[b]			
	combustible	300	m^3	
	processable	135	m^3	
	non-processable	15	m^3	
	ion-exchange residue	23	m^3	
	filters	2.3	m^3	
	spent fuel	195.0	m^3	
	Total	670.3	m^3	
	Emissions[b]			
	Gases and particulates (Ci/week)			
	tritium	0.22.	% DRL	2.2×10^5
	noble gases	0.20	% DRL	2.4×10^4
	iodine	0.02	% DRL	0.4
	particulates	0.07	% DRL	1 Ci/week
	Liquid			
	tritium	0.09	% DRL	1.6×10^7 Ci/week
	other	0.28	% DRL	900 Ci/year

Notes:

DRL – derived release limit (AECB-approved) Emission impact includes world-wide impact.

Combustible wastes are those that could be burned in a special design of incinerator to bring about a large volume reduction.

Processable wastes are materials suitable for compaction, plus those that are nominally combustible, but unsuitable because of high activity content.

Non-processable wastes are miscellaneous pieces of equipment such as valves, piping, etc.

Sources:

a) United States. Atomic Energy Commission. "Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy." Washington, D.C. 1974, table 3.6, p. 3.67.

b) A.M. Aiken, J.M. Harrison, and F.K. Hare. "The Management of Canada's Nuclear Wastes." Ottawa, Department of Energy, Mines and Resources, August 1977, table 4.3, p. 23.

The CANDU reactor is designed on the basis that the fuel passes only once through the reactor core. After the fuel has been used, it is placed in temporary storage, in special tanks near the reactor. It was originally expected that the spent fuel would be reprocessed to extract the plutonium-239, and recycled with fresh uranium or thorium. However, no reprocessing has yet been undertaken and the decision to do so will depend upon a number of factors, including not only the price and availability of uranium but public reaction to the moral and security aspects of a proliferation of the production of plutonium.

The spent fuel from light-water reactors (LWR), which contains not only plutonium but larger amounts of uranium-235, is not yet reprocessed on a commercial scale in the U.S., although some reprocessing is being done in Europe on a pilot scale. In addition to the security risks that are inherent in the reprocessing of spent fuel, huge quantities of liquid wastes are created that still contain small amounts of plutonium as well as heavy metals and actinides.

The characteristics of the spent fuel from CANDU reactors are extremely well known. It is highly radioactive, giving off both particle and penetrating radiations (see Appendix B). It contains unused uranium, fission products such as strontium-90 and caesium-137, and the so-called actinides including neptunium-237 and americium-241. Virtually all the radioactive fission products decay in about 600 years with the exception of iodine-129. Most of the radioactive properties after that time are determined mainly by the actinides, some of which have a half-life of over a million years. Even this is short compared with naturally occurring uranium-235 and -238, which have half-lives of 710 million years and 4,500 million years, respectively.

The key issue is whether irradiated fuel, with these characteristics, can be disposed of permanently in such a way that it will not have a deleterious impact on human health and the environment at any time in the future. In this context, the future to be considered extends for at least a million years.

The kinds of hazard presented by the preparation, transportation, emplacement, and final disposal of spent fuel have been widely studied but are often misunderstood by the public. These four stages are

subject to the same strict procedures and controls that are mandatory in handling all highly radioactive material. Short of gross human error, the health and environmental impacts of the first three stages could be maintained at levels that present no significant hazard over the relatively brief periods during which preparation, transportation, and emplacement in final storage take place.

It is the final stage, in which the irradiated fuel rests in its ultimate disposal site, that is the main source of concern for its potential long-term impact.

The method most likely to be used for disposing of spent fuel, at least in countries such as Canada and Sweden, is encapsulation followed by burial at a great depth in largely impermeable rock. A major Canadian project to this end is described below, and the state of the art in other countries is discussed.

If such a solution were adopted, the isolation of the radioactive material from the immediate environment would depend largely upon the prevention of the migration of radionuclides from the fuel by means of ground-water circulation. This is the only path by which radioactive contamination from the fuel could reach and affect plant, animal, and human life. There would be no risk at all of spontaneous explosions or other unexpected events – just the single risk that the immobilized wastes may be progressively eroded and their radioactivity spread through the ground water into streams and wells. Therefore, research on the permanent disposal of nuclear waste is mainly directed at means of reducing the rate of spread to a stable, negligible level. An impermeable rock site would be chosen, to ensure that the waste was in an area where the rate of ground-water circulation was low. Rocks vary in their ability to absorb dissolved nuclides and thus "filter" them from the ground water. The type of rock and back-fill would be chosen with this in mind. Finally, the spent fuel would have to be encapsulated or vitrified prior to disposal to make it as impervious as possible to dissolution under the conditions of the permanent disposal site, for an indefinite period.

It will be seen that many other techniques for nuclear waste disposal are being studied but all of them have the common aim of isolating the waste for an indefinite period from its surroundings.

At the present time, no country has made provision for the permanent disposal of spent fuel or other highly radioactive solid nuclear wastes. Like nuclear reactor accidents, nuclear waste disposal is a subject that is discussed as much on the basis of emotion as of science.

Up to now the spent fuel from Canadian nuclear reactors has been placed in temporary storage on-site in water-filled, double-walled concrete tanks. Since spent fuel continues to give off decay heat, the water serves to cool it as well as to shield the radioactive emissions. The storage volume needed is of the order of 2 m^3 per tonne of spent fuel and the fuel used amounts to about 130 tonnes per gigawatt year. Hence the storage volume required for every gigawatt year of energy is about 260 m^3 – a space measuring 10 m by 10 m by 2.6 m. Pickering A, which has a capacity of over 2 GW, stores twice this volume of fuel each year. The present storage bays can accommodate all the fuel that will be discharged until at least 1988.

The temporary storage of spent fuel in this way is practised in all countries that use nuclear power. It appears to present few real or potential hazards.

Alternatives under study are dry storage above ground in concrete canisters or in vaults in which the bundles are stacked vertically and allowed to cool by convection. However, none of the existing or proposed methods of on-site storage attempt to solve the long-term disposal problem.

Many studies have been made of radioactive solid waste disposal, including two recent Canadian studies.[30] The variety of disposal methods that have been suggested is considerable. To quote from the Hare report, a study dealing with the management of nuclear wastes published by the federal Department of Energy, Mines and Resources, these include:

(a) Placing in sealed canisters and leaving on the surface of the earth in designated locations where they can be monitored for as long as considered necessary.

(b) Transporting the wastes in suitable containers to the Antarctic or to Greenland where they are buried in the great ice sheets.

(c) Loading them into rockets and firing them to another planet or to the sun.

(d) Depositing the wastes, suitably contained, in the deep abyssal plains of the oceans, either on the sea floor, or buried in the sediments and rocks beneath.

(e) Geological containment on land

(i) Burial in rock salt, either where the beds have been deformed into domes, or in thickly bedded strata of salt.

(ii) Burial in crystalline rocks of igneous origin.

(iii) Burial in shaly rocks of the kind normally associated with limestones and other sedimentary deposits.

(iv) Burial in rocks formed from volcanic ash (tuff).

(v) Burial in other rock types which may be found to be suitable because of particular characteristics.[31]

Many countries are conducting research on one or more of these methods. Excellent reviews of the Canadian nuclear waste disposal problem appear in the *Report of the Cluff Lake Board of Inquiry*[32] and in an AECL report[33] on the management of radioactive wastes. While a detailed review of the work is inappropriate here, it will perhaps be useful to list some conclusions relating to nuclear waste management that seem to be widely accepted. These stem from the Hare report[34], the Uffen report[35], and other literature on waste disposal and were discussed in the *Interim Report* of the RCEPP.

1. There is an urgent need for more intensive research and development on the subject of the permanent disposal of nuclear waste.
2. Guidelines for disposal of high-level wastes need to be developed and promulgated.
3. Temporary storage should continue to be at power stations, not at a central location, in order to avoid unnecessary transportation of highly active material.
4. Deep underground storage in plutonic rocks (like granite) in stable geologic areas appears to be the most promising solution for long-term disposal.
5. Research on encapsulating or "fixing" the spent fuel in a form suitable for underground storage is far more important than research on reprocessing.

A Canadian development and demonstration programme for the management of radioactive wastes, described in an AECL report[36], involves the study of a wide range of vitreous and other materials for the containment of irradiated fuel and of the feasibility of disposing of contained fuel in deep hard-rock repositories. The specific targets of the programme are reported as:

- To verify the basic concepts of disposal of irradiated fuel or fuel wastes in deep hard rock, at least to the stage where there is general acceptance, by 1981.
- To recommend technically-suitable sites for selection by governments and to construct a demonstration disposal repository by 1985.
- To complete the demonstration repository to a stage where the construction of a full-scale repository could be considered by 2000.

According to the AECL report mentioned above:

> Verification of the concept will involve a great deal of laboratory and field research work, including drilling, geophysical surveys, sampling of groundwater and numerous hydrogeologic tests to determine the hydraulic properties of the rock at various depths in six to ten formations, chosen to cover a spectrum of rock types and gross fracture patterns. The data obtained from these investigations, and from laboratory studies of immobilized fuel and wastes, will be used in nuclides from the immobilization matrix, through the rock structure in which it has been emplaced, to the environment and man. It is expected that the pathways analysis will show that almost all the radionuclides will have decayed to harmless daughter products long before they could reach the biosphere. There is a good deal of general evidence from the behaviour of natural radioactive materials to support this belief but, to prove it, specific information is required on the physical, chemical and hydrogeological properties of typical rock structures. The analysis will also identify which types of geologic formation are suitable and which are not. Part of this work will involve the correlation of external surface features with the characteristics of the formation at depth.

The research and development programmes associated with the project include work on the immobilization of irradiated fuel by vitrification and other means, the characteristics of rocks, buffer material, and back-fill, and the design and construction of the repository itself. This will involve a wide range of scientific and engineering disciplines. In order to cover them the project will involve not only AECL but several branches of the Department of Energy, Mines and Resources, the Department of Fisheries and the Environment, university departments, and industry. It will also keep in close touch with similar projects in other countries.

A process for containing radioactive wastes in glass blocks has been tested for over 15 years at Chalk River.[37] These tests have shown that the leaching rate of the glass in water is extremely low. This is encouraging because, as we have seen, ground water is the chief pathway by which radioactivity from nuclear waste, disposed in an underground repository, might reach man and the biosphere.

It should be noted that the glass blocks will be exposed to varying conditions of temperature and pressure if they are disposed of in a deep repository.

Work in the United Kingdom and Sweden also indicates that the optimum solution to "fixing" spent fuel may lie in fusing it into blocks of a vitreous material.

The Fingal/Harvest process developed in the United Kingdom uses alkali borosilicate glass because it is chemically inert, resistant to leaching by water, and stable under exposure to radiation. It can be made at relatively low temperatures (<1,000°C), and the plant can therefore be made of conventional materials. Experiments show that water at 20°C would penetrate the waste thus vitrified by only 6 mm in 1,000 years. British Nuclear Fuels Ltd. expect to have a pilot plant treating real nuclear wastes by 1981 and a full-scale vitrification plant by the late 1980s.

France is even farther ahead. A vitrification plant (l'Atelier Vitrification à Marcoule) opened last year to handle the high-level waste from the Marcoule reprocessing plant. India is not very far behind, with a vitrification plant due to begin operation in 1980.

While the U.S. has, as yet, no firm plans for vitrification on a large scale, it has an "in-can melting" pilot operation run by the Battelle Institute at Hanford, Washington.

In view of the importance of effective disposal of nuclear wastes and the great public concern about potential hazards, Canada's programme for waste-disposal technology, like that of other countries appears to some to lag too far behind the energy-production technology. Moreover, at the current rate it will be many years before the first batches of spent fuel find a safe, permanent resting place. The technical problems are at least matched in magnitude by the social problems. It is possible that anti-nuclear pressures may delay the selection of sites and, consequently, the introduction of safe, permanent methods of waste disposal. Undue delay could jeopardize lives in future generations. With radioactive waste being accumulated at the present rate, nothing can be gained by delaying the development and implementation of safe, permanent storage sites.

In addition to the high-level wastes discussed above, nuclear power stations produce a substantial quantity of miscellaneous wastes, contaminated with nuclear isotopes, that have to be dealt with on a continuing basis. These include contaminated protective clothing, filters, and anything else that has become contaminated in the course of operating and maintaining the stations.

The Hare report commented:

> These solid wastes are stored in concrete boxes, trenches or pipes above and below ground. The designs vary depending on the wastes to be stored, but they are all governed by the guidelines established by AECB. All solid wastes from Ontario Hydro nuclear generating stations are shipped to the storage facilities at the Bruce Nuclear Development. The original storage trenches there are now full and a new waste storage area has been built.
>
> All operators of radioactive waste storage facilities must obtain a licence for construction and operation of such facilities from the AECB and are required to submit quarterly and annual reports giving details on quantities [of materials] and [levels of radioactivity] of wastes processed and stored, environmental monitoring results, abnormal events and any other information that might be pertinent. In this way the AECB keeps watch on the safety of the storage facilities.
>
> We visited the storage site at Bruce and were satisfied that the wastes stored there did not constitute a hazard to the public. We were concerned, however, regarding the length of time that such wastes should be stored in this manner, and whether some, depending on the time required for complete decay, should not be immobilized and transferred to a geological disposal facility.[38]

Another source of concern, in the long term, is what happens to a nuclear plant when it is no longer operational.

Decommissioning of Nuclear Installations

The decommissioning of disused commercial-scale nuclear installations is a problem that has not yet had to be faced. The incident at Three Mile Island has alerted the U.S. authorities, at least, to the necessity of facing it, and the matter will soon become even more urgent there because a number of nuclear facilities will be retired before the end of the century.

The subject of decommissioning nuclear installations will be equally important in Canada. There are not many disposal options. After a CANDU reactor is shut down, probably 30-40 years after it began operation, the spent fuel will be discharged and the heavy water removed. At this point, the reactor will

contain about 10^7 curies of radioactivity. Three options are then available, according to the submission from AECL to the RCEPP:

1. Mothballing: where the reactor building is maintained intact and kept under surveillance for at least 50 years. Mothballing would cost $6,000,000 and require subsequent annual costs of $80,000.
2. Encasement: where all easily removable parts and parts that will remain radioactive for longer than the life of the encasement structure are removed. The encasement structure is then sealed but some monitoring continues. From plant shut-down to encasement will take four years and cost $17,500,000. Annual costs from then on will be $60,000 for up to 100 years.
3. Dismantling and removal: where all material containing radioactivity is removed from the site. AECL estimates that the total lapsed time between plant shut-down and site release will be six years. The cost is expected to be $40,000,000 for dismantling a 600 MW reactor.

However, the fact that the problem must be dealt with on the site means that dangers still exist if the reactor site was unsuitable in the first place for the long-term storage of highly active materials. This could increase the area that must be closed off permanently to other uses, in order to minimize the risk of contaminating the surrounding environment. It is for this reason that the recommendation is strongly made that allowance for decommissioning should be part of the design and operation of all future nuclear plants.

The Impact of New Reactor Developments

Three kinds of development may eventually bring about changes in the technology used for nuclear power generation. They are the development of new types of fission reactors, the development of the breeder reactor, and the establishment of the feasibility of nuclear fusion as a practical means of electric power generation.

AECL has proposed the development of a thorium-uranium fuel cycle with an organic coolant – the CANDU-OC-thorium reactor. It improves fuel utilization by a factor of about 7. It would probably have health and environmental consequences similar to the present CANDU reactors.

The U.S. has conducted experiments with breeder reactors for many years. There is widespread concern about the safety of breeder reactors, partly because they will involve the use of enriched plutonium (by about 20 per cent). The consequences of a breeder-reactor accident could thus be very serious, and there is a fear that once plutonium is produced on the necessary scale there would be a greater risk of its diversion for use in nuclear weapons.

Experiments on nuclear fusion continue in many countries. There is as yet no proof that it can be achieved. Even if there is a sudden breakthrough, it will be many years before electricity-generating plants using this technology will be available. While fusion appears to be a fundamentally clean technology, economic considerations would require that it be combined with the reprocessing of fuel for fission reactors, and this would tend to introduce some of the waste-disposal problems discussed above.

The RCEPP, in its *Interim Report*, concluded that the development of advance fuel cycles by AECL and Ontario Hydro should not have a high priority at this time.

As none of these technologies is likely to be introduced in Ontario within the period surveyed by the RCEPP, they are not reviewed here in further detail.

Summary

The environmental and health impact of nuclear electric power generation is seen to have several components. They include the effects of

- radioactive emanations and seepage from mine and mill tailings
- the transportation and processing of fuel
- radioactive emissions to air and water during normal operation
- the disposal of spent fuel and nuclear wastes
- radioactive emissions and environmental contamination due to accident or sabotage to the reactor
- radioactive emissions and environmental contamination due to accident or sabotage to spent fuel during removal, transportation, and disposal

Table 4.5 summarizes the amounts of material and radiation associated with a 1,000 MW power plant. Taking these in order, the safe long-term containment of tailings is a problem that has not yet been

dealt with satisfactorily. An adequate solution depends not only on technological development but on the economic and political will to ensure that tailings areas are safe for posterity. It should be noted that the greater part of the tailings problem in Ontario is due to the mining and processing of uranium for export. Only about one-fifth of the tailings result from the mining of uranium for Ontario power plants. In other words, if nuclear power generation in Ontario were stopped tomorrow the tailings problem would hardly be reduced.

Transportation of fuel presents few problems because of the relatively small quantity involved. Processing is carried out under controlled conditions and presents no greater-than-normal industrial hazards.

The radioactive emissions to air and water during normal operation are extremely low and are judged to cause a barely perceptible increase in the incidence of cancer in the general population. The occupational hazards in the generating plant have been low compared with those in many other kinds of occupation.[39]

The management of spent fuel and nuclear waste, as carried out at present on a temporary storage basis, is safe and effective in the sense that actions to date cause little risk to present or future generations. This will continue to be true only if safe methods for the permanent disposal of nuclear wastes are developed and implemented.

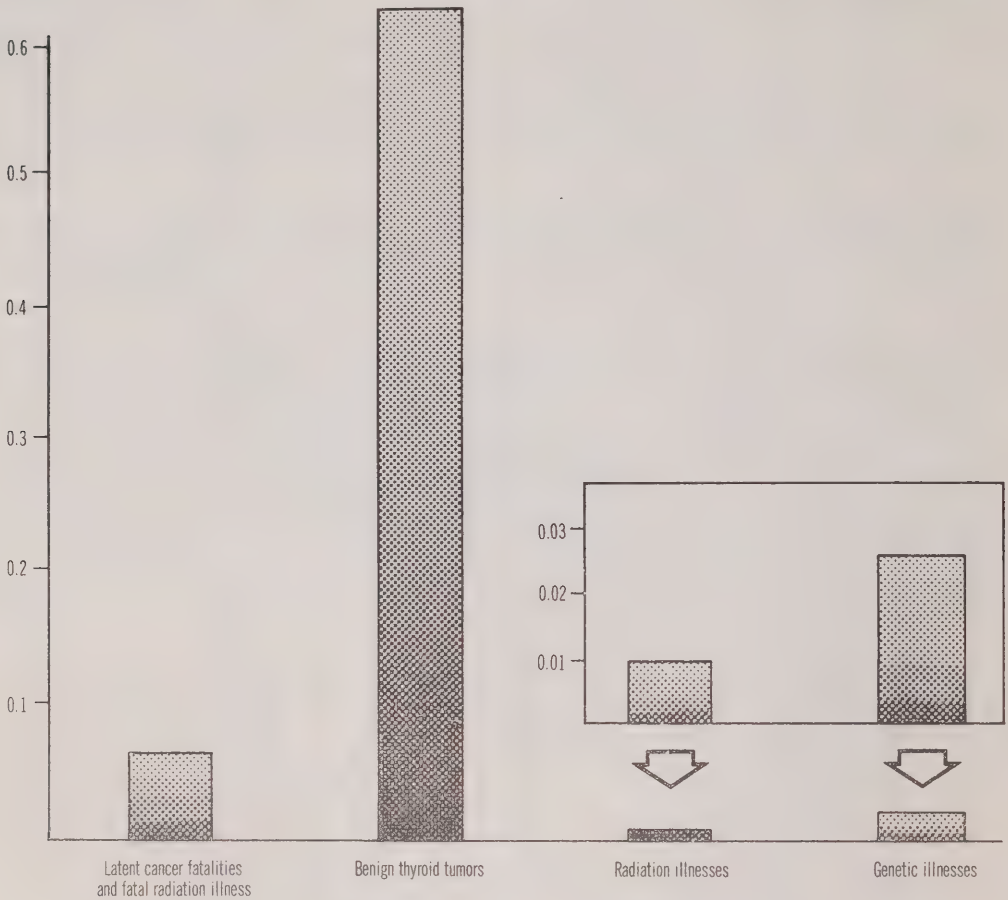
In spite of the reservations regarding tailings and nuclear wastes, the health hazards of the nuclear fuel cycle are quite low when everything is operating normally. They are compared with those of other fuel cycles in Chapter 8. It is the risk of abnormal operation due to malfunction, accident, or sabotage that introduces the greatest uncertainty – an uncertainty that the best minds have failed to resolve.

Comfort can perhaps be drawn from the fact that even the most pessimistic estimates of the annual casualties due to nuclear power are still well below the equivalent estimates for the impact of coal-fired electricity generation. Nevertheless, a nuclear accident is perceived by the public as a fearsome event. To the public, radiation is a mysterious, invisible killer. Cancer is a dreaded disease. It is the nature of the risk, not the probability, that impresses. The public fear is real and must be heeded. Much more and better education of the public might help to mitigate the fear, but it will take decades of safe operation to dispel it.

Figure 4.1 Mines, Mills, and Tailings Areas, Elliot Lake Area

Source: "The Expansion of the Uranium Mines in the Elliot Lake Area, Final Report," Environmental Assessment Board, D. S. Caverly, Chairman, Toronto, 1979.

Figure 4.2 Estimates of Fatalities and Some Illnesses that Can Be Expected to Occur as a Result of Nuclear Power Plant Accidents (Pro-Rated to 3.3 Gigawatt Years of Electrical Energy in Ontario, 1978)



Note: Scale adjusted as indicated in title.

Source: Based on "Unpaid Costs of Electrical Energy", by William Ramsay (U.S. estimates).

CHAPTER FIVE

The Impact of Hydroelectric Power

Hydroelectric plants supplied 37.4 per cent of the electric power in Ontario in 1978 (see Table 1.1). They had 28.4 per cent of Ontario's total generating capacity in that year, a percentage that will eventually fall since there is a limit to potential hydroelectric development. The last remaining large-scale development possibility[1] is in the region of the Albany, Attawapiskat, and Winisk rivers in northern Ontario. While hydroelectric power is generally perceived to be "clean" and indeed presents few hazards to public health, the environmental and even social implications can be substantial, as evidenced by the James Bay development in the province of Quebec. The principal areas of impact are in the reservoirs, in the construction of plant, roads, and dams, and in alterations in water flow that may disrupt long-term natural processes.

Reservoir Effects

The flooding of a very large area to create a reservoir has several effects. It drowns a large area of vegetation and drives animals, birds, and insects from the flooded area to the surrounding hillsides, which may not be their natural habitat. In some cases (e.g., the Upper Mazaruni dam in Guyana), flooding can force farmers to move from good agricultural land in a valley to unproductive land on higher ground. Moreover, it distorts the terrestrial-aquatic balance of the region. The implications of these systemic changes must be studied and fully understood before a new hydroelectric project is launched. Attention should also be paid to the effect on recreational areas.

On the positive side, a reservoir can and should provide new opportunities for aquaculture and for waterfowl. However, care must be taken to avoid the sudden changes in level that will jeopardize the development of a stable natural system, particularly along the shoreline. There could also be opportunities for the creation of new recreational facilities.

Housing, Roads, and Construction

A good deal of industrial activity is necessary to develop a hydroelectric site. This means the construction of roads, railroads, and housing, as well as of the facility itself. It also means the introduction of relatively large numbers of people into a region that is not adapted to receiving them. Many of the activities of man also tend to disturb the ecosystem. Road and air traffic, the noise of machinery, and the activity of hunters can change the feeding and living habits of the wildlife. It is only possible to assess these risks for specific projects, and then only with great difficulty. (These comments apply in varying degree to construction related to coal, nuclear, and other sources of electric energy, but, as there has been relatively little systematic assessment of the associated risks, they are only peripherally recognized in the figures relating to those fuels. They are singled out here because the occupational hazards of hydroelectric power are mainly confined to the construction phase.)

Construction also implies risks of other kinds. Estimates of the occupational risks to workers suggest that these are comparable to those for other kinds of construction and similar, on an equal energy basis, to risks involved in the construction of solar power plants. These estimates[2] suggest 1.5 to 2.6 occupational deaths, 350 occupational injuries, and 21,000 to 27,000 man-days lost due to accidents in the construction and operation of a 1,000 MW facility. Clearly, the impacts thus quantified apply mainly to new projects. Only the impact related to operation and maintenance remains after the project is completed and that is a small and indeterminate fraction of the whole. The hazards related to the transportation of rock and earth, in the above estimates, have been criticized[3] as being exaggerated. The only recognized public risk is the risk of dam failure. The historical data base is far too small to permit any statistical estimate of that risk.

Downstream Effects

The main effects downstream are due to changes in the natural pattern of water flow, thermal changes, the depositing of chemical and biological waste from the construction site, the introduction of new species of aquatic life, and, with these new species, the introduction of new diseases and parasites.

These changes may impede fish migration, affect food supplies, and destroy spawning areas. In physical terms, there can be a silting up in some areas and a loss of regular silt deposition in others. A change

in the distribution of water can affect the wildfowl population. Periods of low water can jeopardize plants and aquatic life and may also have an adverse effect on recreational facilities and property values.

Conclusions

While the development of a large area for hydroelectric power may have a significant adverse impact on the ecology of the region, the worst effects can be avoided by careful planning and management. In this connection, certain recommendations submitted to the RCEPP by Fisheries and Environment Canada are noteworthy, particularly in regard to the potential new development in Northern Ontario:

- Any decision to proceed with hydroelectric power development in Ontario should be made only with a full understanding of potential environmental, social and economic impacts on the area. Environmental consideration should be incorporated at each stage of planning and development.
- A detailed inventory should be made of renewable and non-renewable resources, and an understanding gained of significant ecological relationships in areas designated for flooding. Reservoir management plants should, wherever possible, be designed to fit the reservoir into the natural ecosystem of the area.
- As an integral part of hydroelectric power development in northeastern Ontario, steps should be taken to ensure continued productivity of the lower rivers and the estuary and inter-tidal zone that may be affected by such development.
- Included in decisions on hydro power sites should be consideration of the environmental, social and economic impacts of the infrastructures necessary to support the development site, as well as the impacts of the industrial activity and population growth which such developments will attract.[4]

There is, unfortunately, little further opportunity for hydroelectric development in Ontario. Consequently, the environmental and health impact due to the provision of additional hydroelectric capacity will never be more than a very small fraction of the total for all electric power sources.

CHAPTER SIX

The Impact of Alternative Sources of Energy for Electric Power Generation

Solar Energy

There are several techniques by which the energy of the sun can be converted into electric energy. The principal methods that are relevant to the production of electric energy in large amounts for distribution by conventional transmission systems are biomass, direct solar thermal conversion, photovoltaic conversion (terrestrial or in space), and ocean thermal energy conversion (OTEC). The potential impacts of these central conversion techniques are described below.

There are many who would argue that to harness the energy of the sun in a central location and distribute it by means of transmission lines is, in many instances, an unnecessarily wasteful process that goes counter to common sense and to the changing needs of civilization. The sun is itself an energy-distribution system *par excellence.* Moreover, in many places, sufficient solar energy is available over the area of a residential unit to supply most of the needs of that unit. The widespread use of solar energy in this way would reduce the dependence of communities on distribution networks and thus increase their immunity to interruptions due to extremes of weather, and to accident or sabotage, and would provide secure basic energy supplies in times of war.

There are only two major environmental issues regarding the uses of solar systems to produce electricity. They are the impact of the necessary enormous materials production and construction cycle, which will have its own crop of accidents and its own particular pollutants, and the fact that large areas of land would need to be devoted to the collection of solar energy. These are the main considerations in reviewing the impacts of the several solar energy-conversion methods.

Photovoltaic Conversion

Electric power production on a large scale by means of a large area of photovoltaic cells is still some time away. In spite of the increased price of fuels such as oil and gas, photovoltaic cells with high conversion efficiencies will be needed to provide the economic incentive for the establishment of large installations. Moreover, a great deal of land would be rendered unsuitable for other use. It has been estimated[1] that, under average Canadian conditions, a 1,000 MW solar photovoltaic plant would cover an area of about 70 km^2. It would have no other detrimental environmental or health effects beyond those associated with the production of the very considerable quantities of material. It has been estimated[2] that there would be about one death and some 10,000 man-days lost due to illness and accident in the course of building a 1,000 MW solar photovoltaic power plant, although these figures are contested in some quarters[3] as being too high.

The possibility of using photovoltaic cells in a stationary satellite outside the earth's atmosphere is the subject of serious study in the United States. A light-weight structure of solar cells and mirrors would collect the energy and convert it to electricity. This electricity would then be converted electronically into microwave energy, which would be beamed to Earth and converted back to conventional 60 Hz electric energy for distribution.

One estimate[4] of the land required for a satellite-based collector is 13 km^2 per 1,000 MW of generating capacity.

While existing technology is probably sufficiently advanced to enable such a system to be built, the economics of it depend, as with terrestrial systems, on the availability of high-efficiency photovoltaic cells. Moreover, the energy consumed in the course of constructing either a terrestrial or space solar energy system is so high as to cause a net energy deficit for a period that could extend to several years.

The satellite solar power station does not have the disadvantage of needing a large tract of land. However, there is concern about the hazards created by a high-power, high-intensity microwave beam – particularly if the satellite were to get out of control.

The risks due to material acquisition, fabrication, and construction are likely to be at least as high as those given above for a terrestrial installation.

Biomass

There are three principal sources of biomass that could be used as sources of energy. They are municipal wastes, agricultural wastes (crop residues), and plantations of crops that are grown for the purpose of producing energy in a biomass energy system.

There are two main ways of extracting the energy: the biomass can be burned directly, or it can be processed into a gaseous or liquid fuel.

Municipal wastes would normally be burned, after an elementary grinding and separation process. Present thinking points to the use of wastes as 10 to 20 per cent of the fuel input into the burners of coal-fired power plants. While this would require some modification of current control technologies to avoid the risk of spreading virus and bacteria particles in the flue gases, the risk would be more than offset by reducing the problem of disposing of municipal waste and reducing by 10 to 20 per cent the amount of coal needing to be mined and transported for a given amount of electric energy.

Agricultural wastes from such crops as grains and cotton, together with other vegetable wastes, forest residues, and manure, can be used to produce methane gas. The processes are said[5] to produce very low levels of nitrogen oxides and sulphur dioxide. Emissions to the atmosphere from the burning of agricultural wastes are much lower than those from the burning of coal or oil. Agricultural waste-disposal problems would be eliminated and the need for coal to be mined and transported would be reduced.

The pyrolysis of agricultural residues to produce gas places a demand on water supplies. Advanced systems recycle the water supply and thus reduce that demand. There is a solid-waste-disposal problem in such systems, usually handled by evaporation ponds, which are objectionable but do not constitute a danger. However, there is greater flexibility in the siting of such plants than there is, for example, in the siting of coal-gasification plants, which must be close to the source of fuel.

In addition to agricultural waste, plants that are grown specifically for the purpose could be used for energy production. Very large plantations would be involved. U.S. sources[6] estimate that the production from an area of 200 km^2 would provide energy equivalent to that from one million tonnes of coal. In other words, a 1,000 MW power station, with a load factor of 75 per cent and a conversion efficiency of 38 per cent, would require about 100,000 acres, or 410 km^2 of land. An estimate for Canadian conditions[7] more than doubles this figure, raising it to 1,000 km^2.

Energy biomass plantations are perhaps more appropriate in southern regions and will, no doubt, appear first in the southern United States. One of the principal environmental problems is that of water. It is estimated[8] that the amount of water required for a plantation to service a 1,000 MW power station is about 75 times that required to process the equivalent amount of coal in a coal-gasification plant. The scale of land use and water use for energy plantations can therefore be large enough to change the whole ecology of a region. Nevertheless, the federal Department of Fisheries and Environment[9] has tabled with the RCEPP two Canadian studies which, they say, show a real potential in Ontario in the long term for this source of energy.

Solar Thermal Conversion

Land-based "solar farms" are being studied in the United States and elsewhere. The solar radiation is collected over a wide area and concentrated to heat a working fluid, which is used to drive a conventional steam-powered turbine. Like other energy solar systems, this one is likely to be used first in regions where the average incidence of solar radiation is high. The environmental impact is generally similar to that of photovoltaic systems, except for some differences related to the types of materials and construction. However, analysis of the risks that are implicit in the construction of the systems will be meaningful only when specific designs are available.

Studies are also being made of sea-based "solar farms" where the solar energy conversion takes place on the open seas rather than on land. The solar energy may be used to produce liquid hydrogen or ammonia from sea water. One estimate[10] suggests that a 1,000 MW installation of this kind would require a floating array of 48 modules, each with an area of 1 km^2 and containing 20 solar collector units. It is likely that there would be an increased biological productivity in the vicinity of the floating "island", partly due to the nutrients in deep water that would be brought to the surface. While advantage could be taken of this in terms of food production, the gain might be offset by the need to use biocides to avoid fouling the system heat-exchangers, with a consequent net negative impact on marine life.

The transport of the fuel thus produced would pose safety problems. Liquid hydrogen, like natural gas, is susceptible to accidental explosions during transport. Ammonia is poisonous to marine life, but an ammonia spill at sea would quickly dissipate and would not have the long-term consequences of an oil spill.

The proposals for ocean solar thermal plants include the production of inorganic chemicals from seawater on site. Such production would imply air and water pollution which, while not directly attributable to the generation of electric power, would defile a hitherto relatively clean environment.

Solar Space Heating and Water Heating

The use of solar energy to provide space heating and water heating for individual dwellings, or for low-grade heat in factories, does not fall strictly within the terms of reference of this study. Nevertheless, even though these decentralized applications of solar energy do not contribute directly to electric power production, they could reduce the demand for electric energy and increase the efficiency of the total energy system by conserving electric energy for the high-grade applications for which it is best suited. Once in operation, solar installations would provide energy while avoiding the environmental hazards associated with the production of an equivalent amount of energy from fossil or nuclear fuels.

All solar energy systems, whether centralized or decentralized, are likely to be material- and energy-intensive during the construction phase. A period of several years may be necessary before a net gain of energy is achieved over that expended during construction. Once constructed, a solar installation would have relatively little environmental impact, provided it was sited so as not to obscure neighbouring areas. The current view appears to be that the major environmental impact of the use of solar energy for heating occurs during materials acquisition and processing, and construction, and that solar energy systems are likely to be environmentally benign throughout their operating life.

Summary of the Environmental and Health Hazards of Solar Electric Power Generation

Table 6.1 compares the land requirements estimated[11] to be needed under U.S. conditions for three kinds of solar power plants with those for coal-fired plants. The solar thermal and photovoltaic plants occupy roughly 3 to 10 times the area occupied by coal-fired plants and the mining area needed to provide the same electric power capacity. Biomass plantations would require 15 times more land than a photovoltaic system and about 100 times more land than a coal-fired system to produce the same amount of electricity. The other environmental consequences of central terrestrial solar electric power generation are small. The area needs for solar installations in Canada could be as much as double those given in Table 6.1.

Table 6.1 Land Required for Electricity Production (Solar and Coal: 1,000 MW Plant)

Type of resource	Area (km^2) Resource	Plant	Total
U.S. western coal	1.01	3.84	4.85
Average U.S. eastern and midwestern coal	5.87	4.25	10.12
Solar thermal	–	26.3	26.3
Solar photovoltaic	–	40.5	40.5
Biomass plantation and power plant	645	3	648

Source: United States, Envrionmental Research and Development Agency. "Solar Energy in America's Future". Washington, D.C., March 1977. (Data has been converted to metric.)

Solar plants located in space or on the ocean would create special hazards, which are outlined above. These hazards should be assessed carefully before any such ambitious and costly schemes are considered for the province of Ontario.

The consequences of the construction of solar plants on occupational and public health are discussed in Chapter 8, where available estimates are tabulated. As with hydroelectric plants, most of the impact occurs during the construction phase, but the magnitude of the impact is controversial.

It is highly desirable from an environmental point of view that a greater proportion of Ontario's needs for energy be supplied directly by the sun. However, there are two very strong reasons to prefer the decentralized use of solar energy to the construction of central solar conversion plants or solar farms. The first is that solar energy is distributed naturally and is available (in varying amounts) at any

location. The second is that domestic and industrial installations of solar collectors can usually be located on roofs, or in other places where they will not take up additional land. Central solar power plants would occupy space that is additional to other building developments. Therefore, land use is an important consideration in the choice of solar energy systems.

The advantages of a decentralized solar power system for security against fuel shortages or utility breakdowns are obvious. Moreover, energy independence of the small unit (e.g., household and small industry) removes one of the more powerful reasons for urban concentration. The submission to the RCEPP by Fisheries and Environment Canada stated: "There appears to be little or no potential for, or likelihood of, the production of electricity from centralized solar-powered thermal generators in Ontario."[12]

Wind Energy

Wind is a clean source of energy that has been used for many centuries. Like solar energy, it is naturally diffused and lends itself logically to decentralized use.

Wind power systems cover large areas in a vertical plane – about 5 or 6 m^2 per kilowatt of electric power. Depending upon the design of the rotor, they may sweep a significant land area. Moreover, a certain amount of noise is caused both by air flow past the blades and by the mechanism itself, which would necessitate a degree of isolation from residential areas. Large-scale arrays of rotors associated with a central generating plant could be unsightly and, by altering wind patterns, could affect the local climate. The potential interference with television and radio transmission by moving rotors would also have to be considered.

None of the environmental problems is insoluble. There are no direct health hazards except those associated with construction accidents and with accidents during installation and operation, such as the breaking of a rotor. The most likely application in Ontario is to provide a moderate supply of power in small isolated communities.

According to Inhaber[13], wind energy is comparable to solar energy in its health impact. In both cases the impact is mainly from disease and accidents during the acquisition and transportation of materials and the construction of the plant.

Geothermal Energy

The increased price of oil is making it worth while to investigate the possibility of exploiting the concentrations of thermal energy in the earth's crust. The energy can be extracted either as dry steam or as hot water, particularly where there are underground pressure reservoirs. The heat stored in dry rock is more difficult to extract. One technique is to inject water to produce hot water or steam.

It is estimated[14] that a 1,000 MW geothermal power plant would require a land area of some 30 km^2. Environmental hazards include a small amount of air or vapour-borne particulates, excess brine, and a high concentration of minerals in the hot water. However, the impact can be minimized by returning the water, or steam condensate, back to the ground. This also reduces the likelihood of subsidence.

Experience on minimizing the environmental impact of geothermal plants is being gained, for example, in California and in Italy. While there are some known natural sites in Canada, there has been no intensive exploration and the geothermal potential of Ontario has not yet been examined seriously.

CHAPTER SEVEN

Impacts Common to All Fuel Cycles

Thermal Emissions

A common feature of all electricity-generating systems is that only a fraction of the heat put into them is converted into electric energy. The remainder is ejected from the plant by heating the flue gases and/or the cooling water.

Fossil-fuel plants are 38 to 40 per cent efficient, so 60 to 62 per cent of the heat is emitted into the environment. Of this only a small percentage is in the flue gases; most of it is in the cooling water. Current nuclear plants are 30 to 32 per cent efficient, and 68 to 70 per cent of the heat generated is emitted through the cooling water. Consequently, a 1,000 MW power plant with a 75 per cent capacity factor has a thermal discharge of nearly 2,000 MW_{th} (coal) and 2,350 MW_{th} (nuclear).

The Use of Waste Heat

It would clearly be of great benefit to put waste heat to use. Several circumstances militate against such use. Firstly, it is low-temperature heat, for which there are very limited economically viable uses. Secondly, until recently energy has been plentiful and inexpensive and there has been no incentive to exploit waste heat. Thirdly, Ontario Hydro is in the business of selling electricity, not other forms of energy. Finally, the energy is released in large amounts at few locations, not necessarily where low-grade energy is needed.

It is therefore uncertain whether the waste heat from existing thermal power plants can or will be used to any great extent. However, there is a good possibility of introducing co-generation plants in appropriate locations to satisfy needs for additional capacity. "Co-generation" is the term that is currently used to describe plants that are designed not only to generate electricity but to utilize waste heat in systems that are designed for the purpose. One such use is for district heating. Others are suggested in the submission to RCEPP by Fisheries and Environment Canada, which stated:

> It is appropriate, at this time, to consider designs and plans for making practical use of the low-grade heat from power stations, not as makeshift adjuncts to salvage discarded waste from existing plants, but as integral productive components of plants designed to obtain the maximum total use from the energy system compatible with efficient electricity generation. As part of the planning and design of future energy/electricity systems, a series of pilot projects should be initiated to demonstrate and assess the feasibility, economics, and management problems of using thermal discharges for space heat, industrial processes (e.g., drying), greenhouse maintenance, aquaculture or fish hatcheries, etc. The success of such projects should not, at least in the first instance, be judged on thier market compatibility alone, but should also consider the net environmental and net resource use factors.... The effective use of thermal effluents requires some basic changes in utility responsibility and industrial and market structure, and is an example of the interdependence of energy technology, environmental constraints and costs, institutional practices, and social behaviour.[1]

Whether or not new co-generation plants can be designed to utilize waste heat depends very much on local conditions. Unlike a conventional power plant, the co-generation plant must be located where the low-grade heat can be used. For this reason a successful co-generation plant may well turn out to have a different optimum size than a conventional plant.

The utilization of waste heat is unlikely to cause significant environmental and health effects beyond those associated with the electric power it produces. Indeed, the use of the waste heat could result in its dissipation without the need of costly cooling towers, and avoid some of the impact described in the next section.

Thermal Pollution

Thermal discharges of the magnitude produced by large thermal power plants can affect the local ecology. The discharges from a large number of thermal power plants could have an impact on climate. Although thermal discharges are not currently seen to be a serious problem in Ontario, not enough is known about the effects of small temperature increases on the natural environment to forecast the impacts with precision, especially since they are likely to be different in each case. However, hydrological and biological studies have been carried out in Canada since the early 1960s. They have involved an

extensive investigation of the "thermal plume" caused by the ejection of cooling water into Lake Ontario from the Lakeview Generating Station and the construction of a large thermal-hydraulic model of the portion of Lake Ontario close to the Pickering A Generating Station.[2]

The potentially harmful effects of thermal discharges to the lakes include:

- a reduced level of dissolved oxygen from direct or indirect causes (e.g., the accelerated decomposition of organic waste)
- a change in the balance between desirable and predatory species of fish
- a threat to the yield and survival of young fish
- the confusion of normal cycles caused by fluctuating temperatures
- the excessive growth of algae causing taste, odour, and water-treatment problems

On the positive side, raising the water temperature may extend the navigation season in places where this would be useful, and extend the growing season in fish farms. There may also be an improvement in water quality in some areas due to the circulation induced by the introduction of hot water. This is said[3] to be true of the Toronto inner harbour, due to discharge from the Lakeview Generating Station. However, such apparently beneficial impacts could produce harmful effects on marine bioculture if the temperature is caused to fluctuate wildly by forced or planned outages.

Control Methods

There are various ways of disposing of waste heat other than by releasing it into the living system of the lakes. They include closed cooling ponds, air-cooled condensers, several types of cooling towers, and condenser water discharge at deeper levels. The magnitude of the problem is indicated by the estimate that the cooling pond for a 1,000 MW power plant could occupy an area of as much as 4 km^2.

Cooling towers have been used with success in the U.S. and Sweden and other countries. In a popular type, the cooling water is mixed with air and cooled largely by evaporation. However, there is a risk of the warm air depositing water on the ground and causing stable fog under certain wind and temperature conditions. Thus, the vapour from cooling towers might, under freezing conditions, cause a drop in visibility on nearby roads, accompanied by a buildup of ice. Therefore the use of cooling towers in Ontario might necessitate an increased buffer zone around a power plant.

There is the further danger that the use of cooling towers with fossil-fuel plants would intensify the acid fallout from the reaction of the sulphur dioxide emissions with water vapour from the cooling tower. Dry cooling towers are feasible but only at very high cost, which has so far inhibited their use for large power stations. While no control measures of this kind have been considered necessary in Ontario to date, a watch must be kept to ensure that such measures are introduced before the thermal pollution of the Great Lakes from Canadian and U.S. sources becomes excessive.

Transmission

The electricity that is generated in Ontario power plants is distributed to users by means of overhead transmission lines. For this purpose the power is transformed to high voltage in order to minimize line losses. The voltages used for transmission over significant distances are 115 kV, 230 kV, and 500 kV.

A certain "right of way" is required for the transmission lines. Just as the lower voltages require more circuits for a given amount of transmitted power, so the right of way required for a low-voltage line is wider than that for a high-voltage line providing the same service. Table 7.1 shows the relationship between line voltage, capacity, and right of way, based on transmitting 4,000 MW for 100 miles.

Table 7.1 Right-of-Way Requirements (to transmit 4,000 MW for 1,608 km)

Voltage	Capacity	Number of circuits	Right-of-Way Width (m)	Right-of-Way Area per km (km^2) of length
115	30	133	1,532	1.532
230	140	29	366	0.366
500	2,200	2	61	0.061
765	4,300	1	41	0.041

Source: Ontario Hydro, "Transmission, Environmental." Submission to the RCEPP, Toronto, March 1976, p. 10.

High voltages such as 765 kV are used for some circuits in Quebec and elsewhere, but are neither used

nor projected for use in Ontario for the remainder of this century. The highest voltage now in use in Ontario is 500 kV. The total area occupied by transmission corridors in Ontario can only be calculated from a plan of the entire system. It was estimated[4] at roughly 180,000 acres (728 km^2) in 1975 for a total transmission distance of 11,200 miles (18,025 km).

Concern has been expressed not only about the unsightliness of transmission lines, with the associated pylons and transformer stations, but about other health and environmental effects that might result from the transmission of electric energy at high voltages. The principal hazards that are perceived are summarized below.

Accidents. High voltages are perceived as presenting a risk to small children, for example, when they try to retrieve a ball from a transformer enclosure or a kite that becomes entangled with transmission lines. At a public meeting, one witness stated: "As a mother of three small children I view with grave concern my being forced to live and work under those lines."[5]

Ontario Hydro takes reasonable precautions against accidents to children by erecting fences and putting up danger notices. There is, however, a limit to possible precautions and there is no doubt that the presence of high-voltage transmission lines places some unavoidable additional burden on the parents of children who live in the vicinity of such installations.

The danger of accidents to farmers has also been highlighted in the public hearings: "Although the danger of a child retrieving a ball from a transformer enclosure has been highly publicized by Ontario Hydro, the dangers to a farmer-operation have been kept hidden."[6] Another witness stated: "The use of large machinery close to towers especially at night is very risky." Still another said: "We can definitely conclude that building transmission lines across agricultural land will make farming operations both inefficient and dangerous."

Some of the electric shocks that are experienced are no doubt due to voltages induced in farm machinery, fences, and pipes that are directly in the transmission corridor. The circumstances that can produce such shocks, which are usually unpleasant but not dangerous, are quite well understood. Detailed guidelines on grounding and/or insulation of metal objects and examples of safe and unsafe configurations (e.g., of pipes and fences) are developed and discussed by Ontario Hydro with farmers operating close to transmission lines.

Health Hazards Due to Electromagnetic Fields. While there is concern, particularly in farming communities, over the long-term effects on health of exposure to the electromagnetic radiation in the immediate vicinity of transmission lines, experts do not agree on the extent or even on the existence of such dangers. Nevertheless, while the possibility of health hazards exists the matter must be taken seriously. Ontario Hydro has reviewed[7] the principal research projects related to the health effects of prolonged exposure to low levels of electromagnetic radiation. The results are inconclusive and, in some instances, contradictory. The only study that finds a positive correlation between deterioration of health and exposure to high-voltage fields was conducted in the U.S.S.R., but it seems doubtful whether these experiments were sufficiently well controlled to produce conclusive results. Other experiments on linemen, conducted by researchers at Johns Hopkins University in 1972, failed to produce any evidence of deleterious effects on health and were in some respects directly contradictory to the U.S.S.R. results. Ontario Hydro is currently collaborating with the University of Toronto in research on the subject. Hydro is also following closely otner research projects in Britain, the U.S., the U.S.S.R., and Europe.

As in the case of nuclear radiation, there is controversy as to whether there is a safe "threshold" level below which there is no physiological effect or whether the effects of exposure up to any level, no matter how low, are cumulative over a person's lifetime. Until these questions are answered by research, reasonable steps should be taken to avoid the unnecessary exposure of individuals to the electromagnetic fields from transmission lines.

Sulphur Hexafluoride and Askarel. Two compounds that are used in transformers and switching stations have been identified[8] as potential health hazards. Sulphur hexafluoride (SF_6) is a gas that has no poisonous properties. However, like nitrogen, if it is released in sufficient quantities to replace the air in a confined space, anyone in that space would be asphyxiated. Ontario Hydro assessed the chances of such concentrations occurring in practice as negligible, even under the worst switchgear accident conditions. Their view is supported by the relevant Ontario ministries, and a similar conclusion has been reached by the Institute of Environmental Studies at the University of Toronto.

Askarel is the trade name of a compound that is used in very-high-voltage transformer and capacitor banks. It is used because of its electrical characteristics, which are superior to those of alternative

insulating compounds for high-voltage applications. Unfortunately, askarel is one of a class of polychlorinated biphenyl (PCB) compounds that are not biodegradable, i.e., are not broken down and rendered harmless by normal biological processes. The properties of PCB compounds have been widely studied because of their toxicity and persistence once they enter the food cycle of animals and human beings. Ontario Hydro stated in a submission to the RCEPP:

> Special measures are taken to protect the environment from this liquid. Provision is made to catch any accidental leakage such as at new capacitor locations by use of a sand trap with polyethylene liner. Procedures have been implemented that require regular inspections. The faulted equipment together with all contaminated materials is sent to approved disposal facilities in sealed metal containers. Ontario Hydro, the Ontario Ministry of the Environment and the Ontario Fire Marshal's Office have cooperated in the development of special instructions and procedures for the handling of PCB spills and fires.[9]

The use of PCB compounds will continue for many years until an adequate substitute is developed and all existing components containing it have been replaced. Consequently, special measures to prevent the contamination of water and food by PCB compounds will continue to be essential.

Ozone. Ozone (O_3) is produced from oxygen (O_2) in the surrounding air by electrical ("corona") discharges across transmission line insulators in damp weather.

The potentially damaging effects of ozone on crops and human beings are described in Chapter 2 in relation to the emissions from coal-fired power plants.

Present indications are that the ozone from transmission lines is negligible in quantity from a health and environmental standpoint. This is certainly true in relation to the ozone produced by the nitrogen oxides emissions from fossil-fuelled power plants. The ozone from corona discharges is relatively small in quantity and occurs in locations from which it is quickly dissipated by natural means.

Radio and Television Interference. Another quite different kind of pollution is pollution of the radio-frequency spectrum, particularly of those frequencies on which radio and television signals are transmitted. Corona discharges that fluctuate with the weather and small spark discharges due to imperfect connections radiate energy over a wide band of frequencies including the radio and television broadcast bands. National standards limit the radiation in the AM radio band at a point 50 feet laterally from the high-voltage line. Ontario Hydro claims[10] to meet these standards in fair weather but corona discharges in damp weather still cause some interference to AM signals that is very difficult to eliminate.

FM radio is much less susceptible to interference and appears to be little affected in any weather. TV interference is alleged to come mainly from sparking at faulty connections and not from corona discharges. It can therefore be cured by correcting the fault and is not fundamental to the system.

Maintenance. One of the principal causes of environmental damage in an established system is regular or emergency maintenance. In emergencies heavy equipment must be brought in quickly to service lines or towers, with consequent potential damage to the land. This includes damage to the soil by "compacting" under heavy equipment, direct damage to crops and vegetation, and damage to the appearance of the land in the vicinity. There is a trade-off between performing maintenance in the most economical manner, at one extreme, and producing the minimum effect upon the environment, at the other.

This is equally true of the design of new transmission systems. There are ways of minimizing the width of the right of way by using higher, multi-line transmission towers and using higher voltages. There are less damaging but more expensive means of installation and maintenance, such as the increased use of helicopters. Only a continued dialogue between the utility and the public will determine the extent to which the price of electricity should be increased to finance these costly measures for environmental protection.

CHAPTER EIGHT

A Comparison of the Impacts of Principal Fuel Cycles: Projections to 2000

The likely range of environmental and health hazards of the principal systems for the production of electric energy have been described in previous chapters. Sufficient data are not available, and the methodology for risk assessment is not sufficiently developed, to permit ranking of the systems on a quantitative basis in terms of environmental damage, occupational and public fatalities, injuries, and diseases. The nature of the environmental and health effects varies so much from one system to another that we are continually faced with an apples-and-oranges comparison. Most current estimates of the impact of electricity generation on health are quite low compared with the consequences of traffic accidents, or with the deaths and disabilities that result from the exhaust emissions from automobiles, or from industrial smog, hurricanes, or floods. However, this does not mean that these impacts are, in general, acceptable; their acceptability varies significantly with the nature of the risk and the distribution of risk and benefit, as discussed in greater detail in the section on the interpretation of risk at the end of this chapter.

Because of the complex and not fully understood relationship between the technical aspects of a risk and its social and political acceptability, great caution must be exercised in using environmental and health impact statistics when new capacity is being planned and a choice has to be made from among the various systems for generating electricity.

These difficulties notwithstanding, an attempt will be made here to compare the environmental and health impacts of electricity generation systems based on various energy sources. First, the assumptions that have been made about the development of Ontario's electric power system will be set out in five selected scenarios. Then, the environmental impacts of the nuclear and fossil-fuel cycles, which have been compared on an equal-energy basis in previous chapters, will be summarized and applied to the five scenarios to arrive at an approximation of the actual impacts that may be expected in Ontario.

Before any attempt is made to compare the data on health risks, the pitfalls of such a comparison will be discussed. Health effects of the various electricity generation systems and fuel cycles, which have been presented in previous chapters, will then be summarized and applied to the five scenarios. Through the use of these scenarios, environmental and health effects of the various options for the generation of electricity in Ontario will be compared. The ensuing sections contain a brief discussion of the problems that will be encountered in increasing Ontario's dependence on coal, and of the environmental and health effects to be expected from the use of western Canadian coal, compared with those from the use of eastern U.S. coal. The chapter ends with a general discussion, including some comment on the factors to be considered in evaluating environmental and health risks.

Scenarios

It has been amply demonstrated in recent years that we cannot rely on an extension of past trends in electric power consumption to determine future needs. For example, in 1978, peak-load requirements of the Toronto Hydro-Electric System decreased significantly for the first time since 1911.[1] So it is necessary to hypothesize several alternative growth scenarios in order to arrive at an estimated range of impacts that can be expected to occur as a result of electric power generation over the next 20 years. Also, because the impacts associated with the various generation technologies differ, some assumptions must be made about how electricity will be generated in the future.

Current estimates of growth in demand for electricity in Ontario range from a low of about 2.5 per cent to a high of 5 per cent per year, averaged to the year 2000. Ontario Hydro's load forecast presented in the "1979 Review of Generation Expansion Program" (March 1979) works out to an annual average growth rate of approximately 4.5 per cent to 2000. Growth scenarios that are of interest, then, are 2.5 per cent, 3.5 per cent, and 4.5 per cent per annum.

There are two ways in which the environmental impacts of electric power generation between the present and the year 2000 can be presented. The annual impact for the year 2000 can be estimated, and that estimate then compared with the 1979 impact. Alternatively, the cumulative impact over the 21-year period can be calculated. The former method has been used in the scenarios described below and, where appropriate and meaningful, the cumulative impact is also estimated. The figures used in this

chapter are all derived from the quantitative impact data given in previous chapters. All the qualifications and uncertainties attached to many of the figures should be borne in mind here.

Five scenarios are postulated as possible developments of electric power generation for Ontario. The key variables affecting the impact of the generation of electricity are the rate of growth of the supply of electric power and the technology employed to generate the electricity. Given these variables, the quantities of fuel burned and the resulting environmental, health, and social effects can be estimated. Three annual growth rates – 2.5 per cent, 3.5 per cent, and 4.5 per cent – are considered. Two alternative mixes of generation technology are also considered, as follows:

High Nuclear

In this option, the maximum development of nuclear generation is postulated, providing up to 70 per cent of the total electric energy requirements in the year 2000. All base-load generation is provided either by nuclear stations alone or by nuclear stations together with some hydraulic stations. Intermediate and peak-load generation requirements are more efficiently met by using fossil-fuelled stations and the remaining hydraulic stations. The coal:nuclear ratio of expansion is approximately 1:2.

High Coal

This option postulates the development of nuclear generation in accordance with the programme to which Ontario Hydro is now committed, namely up to and including construction of the Darlington Nuclear Generating Station. Beyond this committed nuclear programme, for each 1,000 MW of additional coal generation installed, expansion of the nuclear generation programme by 500 MW is assumed. Thus the coal:nuclear ratio of expansion is 2:1.

Table 8.1 presents a summary of the scenario assumptions, which are presented in greater detail in Appendix B. At the 2.5 per cent growth rate, the effect is a high-nuclear scenario, because no additional generation facilities are required beyond the already committed programme, which consists almost entirely of nuclear facilities. Indeed, none of the power from Darlington would be required for domestic use until some time after 1990 in this scenario, and a further deferral of several years in the Darlington construction programme would be warranted. At the 2.5 per cent growth rate, a generation mix with a high nuclear component is essentially unavoidable.

Table 8.1 Scenario Assumptions – Electric Generation in the Year 2000

Scenario no.	Scenario type	Average annual growth rate of demand for electricity (per cent per annum)	Generation Mix (per cent of total electric energy produced) Hydraulic	Nuclear	Fossil	Annual fuel consumption Tonnes U.	t.c.e.[a]
1	High nuclear	2.5 (low)	22	57	21	1,800	11.0
2	High nuclear	3.5 (medium)	19	57	24	2,200	14.9
3	High coal	3.5 (medium)	19	46	35	1,800	21.1
4	High nuclear	4.5 (high)	16	69	15	3,300	11.9
5	High coal	4.5 (high)	19	47	34	2,200	27.1

Note a) t.c.e. = tonnes coal equivalent $\times 10^6$ at 3.1 MW·h per tonne.

Consideration was also given to the possible environmental and health effects of alternative generation technologies and of a more even mix of generation technologies. Advanced technologies such as solar photovoltaic or coal gasification are considered unlikely to be ready for large-scale deployment in Ontario by the year 2000, for technical and economic reasons.

It was assumed that biomass generation from virgin plantations would advance to the demonstration project stage, fuelling approximately 200 MW of generation capacity by the year 2000. Virgin biomass generation is therefore not likely to have any significant effect, negative or positive, on the overall environmental and health effects of electric power generation in the short to medium term. Although estimates for plantation land requirements to fuel a 200 MW plant at 75 per cent capacity range from 20,000 to 80,000 hectares, prime agricultural land is not required, and such plantations may be considered an efficient use of Ontario's vast acreages of "marginal" lands.

In order to achieve a more balanced mix of electricity generation, expansion of hydraulic generation by 2,000 MW of capacity was considered. This is the approximate amount of hydraulic generation that can be readily achieved without entering into major diversion projects in Ontario's far north. Taking this

approach, at the 3.5 per cent medium growth rate, the proportion of energy generated by hydraulic power increased from 19 per cent to 23 per cent while that from fossil-fuelled generation decreased from 35 per cent to 31 per cent.

This shift is not large enough to be discernible when calculating environmental and health effects for the province as a whole. In a local or regional context, however, the implementation of renewable and alternative technologies can offer environmental and health advantages, as discussed in Chapters 5 and 6. These options should not be forgotten merely because, in the relatively short time frame considered here, they do not significantly affect our analysis at the provincial level. The scenarios presented here illustrate province-wide effects. Environmental and health considerations will be more sensitive to the type of fuel, the nature of the technology, and the specific location parameters at the local and regional levels of analysis than at the provincial level. Analyses of environmental and health effects at the local and regional levels should be conducted as part of the normal environmental assessment procedures.

Environmental Impacts

Comparison of Fuel Cycles

No sophisticated methodology has been developed for the qualitative assessment of the environmental impact of the various electric energy technologies. The nature and amounts of effluent can be listed, but the probable impact on flora and fauna is usually the subject for qualitative rather than quantitative discussion. The impact on air and water quality is more easily described quantitatively, although what that means in terms of the direct and indirect effects on living systems is still a matter for debate and further research. The amount of land that is rendered unsuitable for other uses can also be specified.

The environmental impact of the coal-electric cycle is largely due to the enormous quantity of fuel and fuel residues. Large amounts of coal dust are carried away from storage piles and from rail hoppers during transportation. There is a risk of the seepage of undesirable chemicals from coal stacks, mine tailings, and slag heaps unless they are very carefully controlled. The other major impact on the environment is due to the emission of oxides of sulphur and nitrogen with water vapour from the chimney stacks of coal-fired power plants. The acid rain and ozone that result from chemical reactions in the effluent can affect plant and marine life many miles away from the source of pollution.

The possible impacts of the nuclear fuel cycle are in three areas. First, there are the mill tailings, which have low but persistent radioactivity, and represent the only part of the nuclear fuel cycle that poses the problem of the containment or disposal of very large quantities of material. The risk is that seepage of radium from the tailings may get into ground water and thus migrate.

Then there is the risk of the contamination of a wide area as a result of reactor failure. In stable atmospheric conditions, and assuming wet weather, an area of 25 km^2 could be contaminated to life-threatening levels. Evacuation of that area within 24 hours would be essential. The emissions of radioactive material during normal operation are controlled so as to produce no environmental effects beyond the perimeter of the plant (or even within it). Most observers regard the probability of reactor failure as very low indeed. This is discussed below in relation to health effects.

Finally, there is the problem of the disposal of spent fuel. There are two ways in which this could have deleterious effects on the environment. If the spent-fuel container were breached during transportation, serious contamination by poisonous chemical and highly radioactive pollutants could occur. However, the precautions taken in the containment of spent fuel are such that nothing short of a highly-penetrating explosive charge would cause such an event. In its ultimate resting place, the spent fuel must be impervious to seepage under a wide range of temperature and pressure, and it must be secure from natural and man-made disturbances, particularly earthquakes and bombings, for a period of many centuries. Otherwise, chemical and radioactive contamination from the disposal site could threaten many future generations.

Little has been said about the natural gas and oil fuel cycles, because they do not enter on a large scale into the present or future scenarios of electricity generation in Ontario. Briefly, natural gas is a clean fuel whose major environmental consequences arise in connection with extraction and pipelines. For oil, the environmental hazards are much greater but also mainly in the areas of extraction and transportation. The environmental consequences of oil spills during extraction from the ocean bed or during transportation by tanker or pipeline are well known. Also, oil differs from gas in that it produces

considerable amounts of effluent from the generating plant, and, in this respect, it is only marginally better than coal.

Many of the causes of environmental damage also pose direct or indirect threats to human health or safety.

Projections for Ontario

Environmental impacts associated with each of the five generation options for Ontario have been estimated in two ways. The impacts that would occur in the year 2000 in each scenario as a result of coal-fired electricity generation and nuclear generation are presented in Table 8.2. Since the environmental impact is directly related to the quantity of fuel consumed, effluent deposited, or land used, the cumulative quantities and usages have also been estimated and are presented in Table 8.3. Of course, the cumulative estimates are less reliable than the one-year estimates, since the former assume that the actual electric power generation will conform, on the average, to the scenario projection over the 21-year period. This assumption could be invalidated if a period of low-generation load growth were experienced, followed by a period of much higher load growth. Such a situation is, in fact, quite likely to occur, and the cumulative impacts presented should only be taken as a rough indication of the scale of the environmental impacts, and as indicators of the relative merits of the scenarios.

Table 8.2 Estimated Annual Environmental Impacts Due to Ontario Electricity Generation in the Year 2000

	No growth scenario	Low growth scenario	Medium growth scenario		High growth scenario		
Impact type	**1979**	**1**	**2**	**3**	**4**	**5**	**Units**
Fuel consumed							
Nuclear	500[a]	1,800[b]	2,200[c]	1,800[b]	3,300[d]	2,200[c]	tonne uranium
Fossil	11	11	15	22	11	28	tonne coal × 10^6 at 3.1 MW·h/tonne
Land use							
Mining and milling[e]	8.1	8.5	11.6	16.4	9.0	20.8	km²
Tailings disposal	0.1	0.5	0.6	0.5	0.8	0.6	km²
Ash disposal	25.0	25.0	34.1	50.0	25.0	63.6	km²
Water							
Mining and milling							
usage[f]	0.73	1.61	1.66	1.61	1.94	1.66	L/day × 10^6
total radium effluent[f]	19.00	41.90	43.20	41.90	50.40	43.20	Ci/day × 10^{-6}
acid drainage	400	400	545	800	400	1,000	tonne
Generation							
cooling water usage	29	72	92	84	122	106	L/day × 10^9
thermal release	11,000	27,000	33,800	32,000	46,000	39,700	$MW \cdot y_{th}$
tritium release	120	240	280	240	400	280	Ci/day
other radiation release	0.02	0.05	0.06	0.05	0.08	0.06	Ci/day
Air							
fly ash	10,000	10,000	13,600	20,000	10,000	25,200	tonne
SO_2	0.5	0.5	0.7	1.0	0.5	1.3	tonne × 10^6
CO_2	22	22	30	44	22	56	tonne × 10^6
NO_x	0.08	0.08	0.11	0.17	0.08	0.21	tonne × 10^6
trace metals	78	78	106	156	78	199	tonne
thermal discharge	970	970	1,320	1,940	970	2,470	$MW \cdot y_{th}$
Radioactive							
tritium	210	420	490	420	700	490	Ci/day
noble gases	37	75	87	75	125	87	Ci/day
iodine 131	3.4×10^{-5}	6.9×10^{-5}	8.0×10^{-5}	6.9×10^{-5}	11.5×10^{-5}	8.0×10^{-5}	Ci/day
particulates	30×10^{-5}	60×10^{-5}	70×10^{-5}	60×10^{-5}	100×10^{-5}	70×10^{-5}	Ci/day
Waste produced							
Mining and milling							
tailings	0.31	1.1	1.3	1.1	2.0	1.3	tonne × 10^6
Generation							
spent fuels	830	3,000	3,700	3,000	5,500	3,700	m³
nuclear solid wastes	1,800	6,600	8,000	6,600	12,000	8,000	m³
total ash	1.3	1.3	1.8	2.6	1.3	3.3	tonne × 10^6

Notes:

a) 3 nuclear stations including Douglas Point G.S.

b) 6 nuclear stations including Douglas Point G.S.

c) 7 nuclear stations including Douglas Point G.S.
d) 9.5 nuclear stations including Douglas Point G.S.
e) Coal component based on an estimate of 60 per cent underground mining, 40 per cent strip mining.
f) Mean value over the 21-year period 1979-2000, uranium mining only.
Source: Developed from impacts presented in Chapters 2 and 4 of this volume.

Table 8.3 Estimated Annual Cumulative Environmental Impacts Due to Ontario Electricity Generation for the Period 1979-2000

Impact type	No growth[a] scenario 1979	Low growth scenario 1	Medium growth scenario 2	3	High growth scenario 4	5	Units
Fuel consumed							
Nuclear	14,000	27,000	32,000	31,000	38,000	32,000	tonne uranium
Fossil	190	190	230	250	260	325	tonne coal × 10^6 at 3.1 MW•h/tonne
Land use							
Mining and milling[b]	140	150	180	190	200	250	km^2
Tailings disposal	9	17	20	19	24	20	km^2
Ash disposal	430	430	520	570	590	740	km^2
Water							
Mining and milling							
total radium effluent	0.15	0.29	0.33	0.32	0.39	0.33	Ci
acid drainage	6,900	6,900	8,400	9,100	9,500	11,800	tonne
Generation							
thermal release	260	420	500	500	590	540	$MW \cdot y_{th}$ × 10^3
tritium release	0.5	1.0	1.2	1.1	1.5	1.2	Ci × 10^6
other radiation release	100	190	210	200	270	210	Ci
Air							
fly ash	0.2	0.2	0.2	0.2	0.2	0.3	tonne × 10^6
SO_2	8.9	8.9	10.8	11.8	12.2	15.2	tonne × 10^6
CO_2	380	380	460	500	520	650	tonne × 10^6
NO_x	1.4	1.4	1.7	1.9	1.9	2.4	tonne × 10^5
trace metals	1,300	1,300	1,600	1,700	1,800	2,300	tonne
thermal discharge	18	18	20	22	23	29	$MW \cdot y_{th}$ × 10^3
Radioactive							
tritium	1.6	1.8	2.0	1.9	2.6	2.0	Ci × 10^6
noble gases	0.28	0.32	0.36	0.34	0.47	0.36	Ci × 10^6
iodine 131	0.26	0.30	0.34	0.32	0.44	0.34	Ci
particulates	2.3	2.6	3.0	2.8	3.5	3.0	Ci
Waste produced							
Mining and milling							
tailings	8.5	16.4	19.4	18.8	23.1	19.4	tonne × 10^6
Generation							
spent fuels	21,000	40,000	50,000	46,000	57,000	50,000	m^3
nuclear solid wastes	50,000	96,000	120,000	110,000	140,000	120,000	m^3
total ash	22.8	22.8	27.2	30.0	31.2	39.0	tonne × 10^6

Notes:
a) The "no growth" scenario assumes continued generation of 95,700 GW•h per year for the duration of this century, but some reallocation away from coal-fired generation in favour of nuclear generation as the full power output from Bruce A becomes available. This is assumed to take place early in 1981. Nuclear generating stations under construction are not included in this scenario.
b) Assumes 60 per cent underground mining, 40 per cent strip mining of coal.
Source: Derived from impacts identified in Chapters 2 and 4 of this volume, using summations of annual fuel requirements for the various average annual growth rates, zero, 2.5 per cent, 3.5 per cent, and 4.5 per cent.

Impacts incurred in 1979 are given in all tables, for ready comparison. In Table 8.3, the first column presents the cumulative impact that would occur by the year 2000 if no further growth in electric power demand, beyond the 1979 level of electric energy consumption, were to take place.[2] This allows for a direct appreciation of the overall impacts attributable to the growth in electricity generation to the year 2000.

Impacts of Coal-Fired Generation in 2000

Land-Use Impacts. From Table 8.2, it may be seen that the total area needed in the year 2000 to accommodate the generation of electricity from coal in Ontario is likely to range from 34 km^2 (3,400 hectares) for scenario 1 to 85 km^2 (8,500 hectares) for scenario 5. The average annual land requirement

over the period 1979-2000 ranges from 28 to 48 km^2. Approximately 75 per cent of this land area will be required for storage of ash from coal-fired generation near the generation sites. The remaining land requirements occur at the mine sites which, for Ontario's coal, are located primarily in Saskatchewan, Alberta, British Columbia, Pennsylvania, and West Virginia. The only land requirements for the mining of coal in Ontario relate to the Onakawana lignite deposit, which will disturb some 25 to 30 km^2 of land. One advantage of the proposal to operate a thermal electricity generation plant at the site of the lignite deposit is that land requirements could possibly be reduced by depositing at least some of the waste ash at the mine site.

Although land-use for the mining of coal does not at present affect Ontario directly an indirect effect is sure to be felt. Concern over environmental despoliation by strip-mining is leading to stricter regulation of land reclamation practices, which contribute to the increasing cost of coal. In some instances, this concern could act to limit the availability of coal deposits in environmentally sensitive or aesthetically unique areas.

Water Impacts. The drainage of sulphuric acid from coal and ash piles in the quantities indicated for any of the scenarios in Table 8.2 does not present major problems, since control mechanisms for acid neutralization are readily available. With respect to thermal discharges and the large quantities of cooling water that are needed, Ontario is fortunate to have in the Great Lakes system large quantities of water. These demands for cooling water must, however, be assessed in the contest of the increasing demand for Great Lakes water on both the Canadian and United States shores. The effects of energy production on the Great Lakes were identified in a 1976 study by the Great Lakes Basin Commission as a major component of any water resources plan for the Great Lakes.[3]

Ontario's total cooling water requirements for electricity generation plants will more than double and could increase by a factor greater than four by the year 2000. Should similar increases be experienced in American states with Great Lakes shorelines, thermal releases from generating plants could begin to have significant effects on the aquatic environment in some of the lakes' littoral zones.

The 1978 Great Lakes Water Quality Agreement between Canada and the U.S. includes thermal pollution in its list of pollutants to be controlled, and there are regulations governing the temperature of effluents relative to the receiving waters (see Chapter 9). These regulations cannot, however, limit the total quantities of thermal discharge which, as Table 8.3 indicates, can be immense. Careful ongoing monitoring of the effects of thermal releases, with a view to optimizing plant and effluent system designs to minimize negative effects is of the greatest importance. Every effort must also be made to harness this wasted thermal energy for productive purposes. Effects of thermal releases need not always be negative, however. Fish farming, district heating, and greenhouse heating have been suggested as uses for waste heat from generating plants.[4]

Air Impacts The major concerns about sulphur dioxide, nitrogen oxides, and carbon dioxide that are expressed in Chapters 1 and 2 are emphasized in Table 8.2 which shows the massive quantities of these pollutants that are produced by just one sector of the energy industry in Ontario. The quantities are in the order of millions and tens of millions of tonnes per year. Control mechanisms are well developed only for sulphur dioxide emissions, and then at considerable cost. Furthermore, flue gas desulphurization simply transforms the sulphur in air into either a solid or a liquid waste, which must still be disposed of in some fashion. There is no market at present for sulphur or sulphuric acid in such large quantities.

Fly-ash particulate emissions are readily controllable by means of electrostatic precipitators. Recently, however, the National Oceanic and Atmospheric Administration has reported that electrostatic precipitators create plumes of highly charged particles that may affect microphysical processes involved in the production of rain, and are often strong enough to produce corona (induced electrostatic field) from leaves and pine needles. Corona can produce some noise as well as radio and television signal interference to nearby receivers. It is also reported that electrostatic forces increase the rate of deposit of charged particles in the human lung.[5]

It is difficult to assess the effects of these various pollutants in the atmosphere, particularly since they combine with one another to produce synergistic effects. Trace metals such as mercury and selenium

are of particular concern in the long run because of their relative persistence and resulting accumulation in the biological food chain. A general principle, in the absence of complete knowledge of cause-effect relationships, is that controlled disposal of contaminants is to be preferred to haphazard deposition into the environment. Coal consumption for electric power generation will represent between one-half and two-thirds of the entire coal consumption in Ontario by the year 2000 (Appendix B, Table B.1). This strongly suggests that Ontario can no longer delay the implementation of measures to reduce sulphur emissions at coal-fired generation plants, particularly in view of the increasing international concern over the effects of acid rain. Options that must be given consideration include increased use of municipal wastes mixed with coal as a fuel, greater reliance on low-sulphur coals from western Canada, and flue gas desulphurization.

Impacts of Nuclear Generation in 2000

Land-Use Impacts. Land requirements for uranium mining and milling are significantly smaller than those for coal mining, even in scenario 4, which is the option with the greatest amount of nuclear generation and the least coal generation. An estimate of the total tailings disposal area required for the Elliot Lake mines is given below in the section on cumulative impacts. From this estimate, it is concluded that approximately 0.25 km^2 is required for disposal of the tailings from 1,000 tonnes of uranium fuel production.

Waste-disposal land requirements for the nuclear and coal fuel cycles differ in two important respects. First, the land requirements for the nuclear fuel cycle are better described as water requirements, since tailings disposal sites consist of lakes reinforced by man-made dams to create water-filled containment areas. As a result, contamination of water by waste disposal is of much greater concern in the nuclear fuel cycle than in the coal fuel cycle. Second, the waste-disposal areas for uranium tailings are situated in the vicinity of the mine sites, not near the generation sites. Land-fill sites for the disposal of coal ash are frequently located on arable land, near major population centres, and are becoming increasingly difficult to find.

Water Impacts. Major water-related impacts of the nuclear fuel cycle occur in connection with water usage, radiation release, and thermal release. In comparison with the cooling water needed by thermal generating stations, mine and mill water requirements are small. It must be remembered, however, that these latter water supplies are taken from much smaller bodies than the Great Lakes, sometimes with damaging impact. The degradation of the Serpent River system, described in Chapter 4, illustrates this clearly. Cooling water requirements have already been discussed in connection with the impacts of coal-fired generation, but most of the cooling water requirements are for nuclear generation plants. Even in scenarios 3 and 5, which have the highest proportions of coal-fired generation, 70 per cent of the total cooling water requirement is for nuclear plants. To put these quantities in perspective, the total cooling water needed for scenario 4 in the year 2000 is 25 per cent of the average daily flow over Niagara Falls. When it is considered that this volume of water would be heated by an average of 10°C in the once-through cooling process, the magnitude of the thermal discharge becomes evident.

Because water impacts associated with uranium mining and milling are expressed in the scenarios as average daily values over the 21-year period 1979-2000, it is useful to compare these figures with the average daily values over the entire 30-year life cycle of the generating stations. In this way, the bias resulting from the relatively low nuclear generating capacity at the beginning of the period is overcome. When these life-cycle average impacts are computed, they range from 20 per cent higher (scenarios 1 and 3) to 80 per cent higher (scenario 4) than the values shown in Table 8.2.

The major release of radiation into water results from tritium released, during routine operations, into the Great Lakes from nuclear generating stations. Since the Atomic Energy Control Board's derived release limits are the same for each generation site, regardless of the size and number of generating stations on each site, the allowable releases vary with the number of generation sites assumed for each scenario. Actual releases have been a small fraction of the derived release limits. In calculating the quantities of tritium released, for Table 8.2, it was assumed that historic release levels at the Pickering Generating Station would be equalled at all future generating stations. The estimate by Fisheries and Environment Canada[6] that "the build-up of tritium in the Great Lakes from Ontario Hydro's future nuclear operations predicts Lake Ontario tritium levels to increase from the current 400 pCi per litre to about 2,000 pCi per litre by the year 2000" is most likely based on a generation expansion programme slightly larger than that assumed for scenario 4, but serves to illustrate the effect of the releases presented in Tables 8.2 and 8.3. On the basis of this estimate, even with no additional nuclear expansion

beyond the committed programme (i.e., scenarios 1 and 3), the level of tritium in the Great Lakes can be expected to more than triple by 2000. The effect of this is estimated by Fisheries and Environment Canada to be an increase in per capita radiation dose from drinking water to 0.3 mrem per year, or 30 per cent of the maximum set by a U.S.-Canada bilateral agreement.

Other Impacts. Impacts on the atmosphere from nuclear generation are directly related to the number of generating stations, which, at the maximum, would triple by the year 2000. These impacts are not of major concern, except in the event of an accidental release from a nuclear plant, when areas as far as 50 km downwind may be contaminated so severely that they are unable to support life for several months.[7] Solid wastes resulting from the generation phase of the nuclear-electric fuel cycles, including spent fuel, could amount to 17,500 m^3 annually by 2000. This is equal in volume to a 26 m cube, which by itself is not unmanageable. The technical problems of spent fuel disposal are not yet solved, however, and these must be given priority attention, as noted in Chapter 4.

The effects of heavy water production have not been included in this discussion. No evidence about the detailed environmental effects of heavy water production was presented to the RCEPP, and our review of the literature did not yield operational data upon which projections could be based. The Canadian literature is sparse, and U.S. reactors do not employ heavy water. From a health standpoint, the major concern is with the potential for large releases of hydrogen sulphide, which is a highly toxic gas.

Cumulative Environmental Impacts — 1979-2000

The cumulative impacts of electric power generation for the five scenarios and for the baseline "no growth after 1979" case are presented in Table 8.3.

Land-Use Impacts. From the report of the Environmental Assessment Board on the expansion of the Elliot Lake uranium mines, the current and projected Elliot Lake tailings areas appear to occupy approximately 20 km^2 (see Table 4.1). If the buffer zone of 2 km around tailings sites recommended by the Environmental Assessment Board is included, this area increases to approximately 100 km^2.[8] Of this, about one-half (50 km^2) consists of new tailings areas. Since Ontario Hydro's uranium requirements take up a maximum of 20 per cent of the Elliot Lake production, it is estimated that tailings disposal areas attributable to the utility's nuclear electricity generation will occupy some 10 km^2, or 0.25 km^2 per 1,000 tonnes of uranium fuel production. Tailings area requirements per tonne of fuel production will, of course, vary with the grade of uranium ore being mined. This is quite a small area compared with the area required for coal waste disposal. It has been pointed out that the main disadvantage of coal in comparison with uranium, insofar as land use is concerned, stems from the location of their respective disposal areas, and not so much from the size of the areas required.

From Table 8.3 (scenario 1) it may be seen that Ontario must have at least 430 km^2 available, primarily in southern parts of the province, for the disposal of ash. The critical question is, how much more land is available for ash disposal in suitable locations close to generating stations? Opposition to large land-fill sites has been increasing, and approvals for such sites could become as contentious and difficult as those for generation sites and transmission rights of way.

Land requirements for nuclear waste disposal and for hydraulic power development have not been considered. Nuclear waste-disposal facilities could occupy significant land areas, virtually in perpetuity but located in relatively remote areas. Some of the remaining hydraulic developments postulated in scenario 5 are located in southern Ontario, where the displacement of agricultural land by reservoirs is a contentious issue. From the land-use perspective, then, the high nuclear options (scenarios 1, 2, and 4) appear most benign.

Water Impacts. With respect to water impacts, little difference is apparent from Table 8.3 between the high-nuclear and high-coal options, in either the 3.5 per cent or the 4.5 per cent growth scenarios. This is somewhat deceptive, however, because of the relatively short span of time being considered. If cumulative impacts were calculated farther into the future, the relative and absolute cumulative impacts of the various scenarios would change considerably. As the nuclear and coal generation systems expand, quantities of waste products are deposited into the environment in each successive year. Cumulative quantities of radioactive wastes increase more rapidly with each passing year for high- nuclear scenarios than for high-coal scenarios. The converse is true for acid drainage. As the target ratio for coal-to-nuclear generation is achieved (see previous discussion of scenarios), the relative quantities of contaminant deposited into the environment each year as a result of coal-fired and nuclear generation will occur in the same ratio.

With the exception of acid drainage, water impacts are in all cases more severe in the high- nuclear scenarios (2 and 4) than in the high-coal scenarios, but only marginally so. The concern about tritium among radioactive releases has already been noted. Although they are smaller, the radium releases should not be overlooked, in view of the long half-life of radium-226 and the toxicity of many of its daughters. The long-term stabilization of radium in tailings ponds is a requirement that has not yet been conclusively fulfilled. Radium levels in the Serpent River near Elliot Lake have in the past reached levels well above drinking-water criteria, and it is not inconceivable that, in the long term, these levels could rise again. Radium uptake in plants and movement through the food chain are not clearly understood and require further research.[9]

Air Impacts. The radioactive releases into the air, by-products of the nuclear generation components of each scenario, appear insignificant in comparison with the huge emissions of oxides of sulphur, carbon, and nitrogen, and of ash and trace metals that result from the coal generation components. Apart from the problems of acid rain and of carbon dioxide, which could have a major climatic effect on the entire world, the significance of these effluents stems largely from their effects on the health of the general population. These effects will be discussed in the next section. It is noteworthy, however, that total sulphur dioxide emissions during the period 1979-2000 range from 35 per cent to 60 per cent of the emissions from the International Nickel Company stack in Sudbury, the largest single source of sulphur dioxide emissions in North America. This stack will emit approximately 25 million tonnes of sulphur dioxide in the period 1979-2000 if current emission rates are maintained. An argument in favour of flue-gas desulphurization (FGD) at Inco must therefore also be considered an argument in favour of FGD at coal-fired generation plants.

Waste Management. Table 8.3 shows that the total quantities of ash and tailings for the five scenarios never differ by more than a factor of two. By contrast, surface area requirements for their respective disposal vary by a factor of 20 or more. This suggests that more efficient means of ash disposal should be investigated to reduce land requirements. Even in the highest nuclear generation scenario, nuclear solid waste including spent fuel for the 21-year period amounts to only 200,000 m^3, or the volume of a 58 m cube. This is not an unmanageable quantity.

Health Impacts

Quantitative estimates of the health effects of the nuclear and fossil-fuel cycles and of some other means of generating electric power are summarized in Table 8.4. Before discussing the figures in the table, it is essential to place severe reservations on the validity and usefulness of such data. In particular, the figures are not necessarily comparable from one fuel cycle to another, for the reasons given below. Therefore they should not be used in a facile manner to rank one fuel cycle or energy source against the others. However, given a background of how the figures were derived, they may be used to supplement a qualitative discussion of the health aspects of future electric power scenarios.

Table 8.4 Comparison of Estimated Annual Health Impact for 1,000 MW Power Plants Using Different Energy Sources (75% CF). Data are based on Tables A2 to A9, Appendix A of this volume.

Impact	Coal	Oil	Natural gas	Nuclear	Hydro	Solar photovoltaic
Occupational						
fatalities	1.5–7	0.14–1.4	0.1–0.3	0.1–1.0	1–2	see
disabilities	26–160	12–100	5–50	5–20	265	text
equivalent man-days lost	14,000–55,000	2,250–14,250	1,400-5,000	2,000–9,000	15,000–20,000	3,750–10,500
Public						
fatalities	1.6–100	1–100	see	0.01–0.5	0.8–1.2	see
disabilities	750–190,000	150–100,000	text	see text	0.8–9.6	text
equivalent man-days lost	15,000–1M	5,000–1M		200–52,500	5,00–7,500	675–1,650
Total						
fatalities	3.1–110	1.1–101	0.1–0.3	0.11–1.5	1.8–3.2	see
disabilities	780–190,000	160–100,000	5–50	see text	275	text
equivalent man-days lost	24,000–1M	7,250–1M	1,400–5,000	2,200–61,500	20,000–27,500	4,425–12,150

The Pitfalls of Comparison

One of the principal pitfalls in estimating the health effects of generating a certain amount of electricity from a particular energy source results from the difficulty of defining what constitutes the system. Clearly, a comparison between different fuel cycles is most effective if all stages are taken into account, from exploration through extraction, processing, transportation (not only of fuel but of materials), construction, operation, and eventual decommissioning of the plant and the safe disposal of all waste products that result.

To go back into all the health costs of construction and transportation would require an analysis of the entire North American industrial and transportation systems. Therefore, researchers on health effects have had to draw the line arbitrarily between those items that are clearly dedicated to fuel production, transportation, and electric power generation and those that are inextricably lost in the maze of other industrial activities.

Unfortunately that is not good enough. While all electric power systems involve the construction of facilities, it happens that the greater part of the health hazards of certain technologies, including hydroelectric and most of the so-called alternative technologies such as wind and solar, produce almost all of their environmental and health impact during the materials and construction phase. Solar power, for example, requires far more materials and a much greater construction effort per kilowatt hour generated than either coal-fired or nuclear power.

There are, of course, different health hazards associated with the production of different materials. Consequently such estimates as have been made of the hazards of alternative technologies are crude and controversial. The estimates of the health effects of coal and nuclear power generally, but not always, exclude estimates of the impact of the component-manufacturing and plant-construction phases on occupational and public health. In the case of coal, these are thought to be small compared with other health effects. For other technologies, even nuclear (excluding reactor accidents), impacts related to component manufacturing and plant construction may constitute a significant proportion of the total risk, even though the total impact is very small in comparison with the occupational and public health risks from causes other than electric power generation.

One of the weaknesses of all the estimates of health effects to date is that they are measured either in terms of fatalities (premature deaths), or disabilities due to injury or disease (without distinction between disabilities of different severity). G.H. Whipple writes:

> In spite of the best medical efforts, every human being eventually dies; only the time and manner of death are in doubt. When one states that the production of 1 megawatt-year of electricity by burning coal entails the loss of a certain number of lives, he means that this number of people will die sooner than would be the case if this energy were not produced. For some of these individuals "sooner" means the loss of many years of productive life, while for others the loss will be only a few unrewarding years. . . . It appears that years of productive life lost is a better measure of "health effects" than the number of persons dying prematurely.[10]

Most published attempts to quantify the loss of productive life have used the U.S. National Safety Council figure of 6,000 man-days lost as equivalent to one fatality, and varying numbers of days lost as equivalent to a disability.

In these respects, also, the data that are summarized below may not be comparable from one fuel cycle to another. Finally, there is the risk of giving too much weight to health impact figures as the basis for the selection of one electric energy system over another. If there are two systems, one of which has 10 times the health impact of the other, it is tempting to select the one that is apparently less harmful. Selection on this basis is only valid above a certain level of health impact. If both systems are relatively harmless the fact that one is 10 times more harmless than the other is irrelevant.

Much more work needs to be done on developing an "index of harm" before thresholds can be set and meaningful comparisons made. Moreover, care has to be taken that the reduction of one risk to health does not introduce others.

> Efforts to eliminate one risk seem, in a number of cases, to enhance or bring on other risks. It's a little like trying to pack a balloon in a box; when you push down in one place, the balloon bulges out somewhere else. Efforts to reduce the risks of producing energy, in part by not producing energy (i.e., conservation), appear likely to increase other risks, e.g., increased levels of radon in houses, reduced street lighting, and the catalytic converters on automobile exhausts. These and other similar side effects make a risk-free society difficult to attain.[11]

Comparison of Fuel Cycles

Table 8.4 summarizes representative estimates of the health impact of various kinds of electric power systems in terms of occupational and public fatalities, injuries, and equivalent man-days lost. The data are summarized from Tables A.2 to A.9 in Appendix A, in which the estimates from various identified sources are presented for comparison. The limitations of these data are emphasized in Chapter 6 and are further discussed in Appendix A.

The health effects of all the principal fuel cycles have been discussed in the chapters devoted to them. The details will not be repeated. Only the main sources of health hazards and the areas of uncertainty will be highlighted.

On the basis of Table 8.4, the health impacts of generating electric energy from coal and oil appear to be substantially greater than those from any other system, including nuclear. The occupational impact for coal is due very largely to accidents and black lung disease in the mines and to the transportation accidents that are inevitable in moving thousands of coal hopper cars to coal-fired plants in Ontario. The public health impact of coal is mainly due to the emissions of the oxides of sulphur and nitrogen, with some hydrocarbons, particulates, and water vapour in the flue gases of the generating stations.

It is difficult to separate the effects of these effluents from the effects of industrial effluents, automobile exhausts, and other atmospheric pollution. All contribute to the incidence of diseases of the heart and lungs and of cancer. Consequently, estimates of the impact vary. The very great uncertainty about the impact of these emissions on public health is responsible for the wide range of values in the public health impact for coal in Table 8.4.

It should be noted that the uncertainty associated with coal-fired electric power stems from the lack of knowledge about the extent to which a generation plant in normal operation affects human health.

The uncertainties associated with a nuclear plant are just as great but are quite different in nature. Most sources agree that the occupational and health impacts of a nuclear plant in normal operation are substantially lower than those for fossil fuels.

With nuclear power however, the great uncertainty that exists centres around the probability, extent, and consequences of departures from normal operation due to malfunction, operational errors, accidents, or sabotage.

In Table 8.4, the figures for public fatalities correspond to those expected due to the normal operation of a 1,000 MW nuclear power plant for one year, with allowance for the extremely low probability of nuclear accident of the same order as that calculated in the Rasmussen Report (1975). However, the figures for equivalent public man-days lost correspond instead to a recent publication of Holdren et al. (1979) who, in criticizing the Inhaber Report (1978), call for a greatly extended range of uncertainty in the figures without, however, coming down in favour of the higher figures. It is an interesting fact that the nuclear fuel cycle is so carefully controlled and monitored that, apart from the probability of accident, few sources attribute significant adverse health effects to radioactive emissions at any part of the fuel cycle, including the containment of mill tailings and the disposal of spent fuel. It is clear that such confidence will only be justified if the temporary measures currently used to deal with these two problems are supplemented by permanent containment and disposal methods that are guaranteed to remain effective for centuries.

These considerations and qualifications concerning the data should be kept in mind throughout the remaining discussion in this section, which projects the health impacts attributable to electricity generation in Ontario to the year 2000 for the five scenarios described in Appendix B.

Projection of Health Impacts to 2000

Health impact estimates vary greatly, making it difficult to offer a definitive comparison of alternative scenarios on the basis of health impacts, partly because the range of the estimates far outspans the differences among the options being compared. One is therefore reduced largely to a comparison of upper and lower bounds and to qualitative discussion of the health impacts of the scenarios under consideration.

Because of the lack of confidence in the data on the health impacts of hydraulic generation, these are presented in the tables in Appendix C only, and are not included in the calculations of total health impacts for each scenario. Some additional man-days lost due to hydraulic generation should be considered probable, especially for scenario 5 in which a 25 per cent increase in hydraulic generation is

assumed, but these impacts would be quite small under normal operating conditions and in years when there is no construction activity.

This section presents a discussion of the variations in occupational and public health impacts among the five scenarios, followed by a brief comparison of the scenarios from the standpoint of overall health impact. Table 8.5 presents the annual health impacts attributable to fossil-fuelled and nuclear generation in Ontario for 1979 and for the five scenarios. A more detailed breakdown of these figures is given in Appendix C, along with the corresponding impacts attributable to hydraulic generation. Table 8.6 presents these impacts in terms of per capita percentage rise or decline in comparison with 1979 levels, assuming a 30 per cent increase in population during the period 1979-2000. This rate of increase is based on the medium projection variant developed by the Ontario government's statistical branch (unpublished), which has forecast a population of 11 million in Ontario by 2001. Tables 8.5 and 8.6 incorporate the same assumptions and estimates of effects of accidental occurrences at nuclear plants as are used for Table 8.4.

Table 8.5 Estimated Annual Health Impacts of Alternative Electric Generation Scenarios

Impact Type	1979	2000 Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Occupational						
deaths	8.2–41	9.2–51	13–70	17–88	11–66	21–110
disabilities	160–920	210–1,120	280–1,500	350–2,000	280–1,400	410–2,400
equivalent man-days lost (× 10^3)	81–330	100–420	140–550	180–710	130–540	220–900
General Public						
deaths	8.4–520	8.5–530	11–710	17–1,000	9–570	20–1,300
disabilities	a	a	a	a	a	a
equivalent man-days lost (× 10^3)	27–5,200	29–5,700	39–7,000	55–11,000	33–7,000	68–14,000
Total						
deaths	16–570	18–580	24–780	34–1,100	20–640	41–1,400
disabilities	a	a	a	a	a	a
equivalent man-days lost (× 10^3)	110–5,600	130–6,200	180–8,300	230–12,000	120–7,500	290–15,000

Note a) Meaningful estimates not available.
Source: Based on data presented in Chapters 2 and 4, of this volume, and pro-rated to correspond to fuel consumption levels indicated in Table 8.1.

Table 8.6 Estimated Annual Per Capita Health Impacts of Electric Generation Scenarios in the Year 2000 – Per Cent Increase Over 1979[a]

Impact type	Low growth Scenario 1 %	Medium growth Scenario 2 High nuclear %	Scenario 3 High coal %	High growth Scenario 4 High nuclear %	Scenario 5 High coal %
Occupational					
deaths	–10	25	60	15	100
disabilities	–5	30	70	25	100
equivalent man-days lost	–5	30	70	25	110
General Public					
deaths	–20	5	50	–15	90
disabilities					
equivalent man-days lost	–15	5	60	0	100
Total					
deaths	–15	10	55	–10	95
disabilities					
equivalent man-days lost	–10	20	65	–5	105

Note a) Figures are based on an assumption of 30 per cent increase in Ontario population from 1979 to 2000. All percentages are rounded to the nearest 5%.
Source: Derived from Table 8.5, of this volume.

Occupational Health. The tables in Appendix C illustrate that, for most scenarios, the fossil-fuel cycle accounts for upwards of 75 per cent of the occupational fatalities and disabilities encountered. Even for scenario 4, with the highest nuclear-coal generation ratio, fossil-related occupational health impacts still represent 70 per cent of total disabilities in the year 2000.

In Table 8.5, the equivalent-man-days-lost entry represents an estimate of fatalities and disabilities combined into a single measure. It may be seen that, at the low end of the range, equivalent occupational man-days lost are expected to increase by between 20,000 and 140,000. At the high end of the

range, the increase ranges from 90,000 to 570,000. But these figures are difficult, if not impossible, to comprehend.

Table 8.6 permits a more meaningful interpretation. Here, it may be seen that, in the period 1979 to 2000, per capita occupational impacts are expected to decrease slightly in the low-growth scenario, and may rise by between 25 and 110 per cent in the medium- and high-growth scenarios. In the high-growth scenarios, the difference between coal- and nuclear-related impacts is emphasized. If a longer projection period were considered, the percentage difference between scenarios 2 and 3 would increase. The decline in per capita impacts shown for scenario 1 results from the change in generation mix from 1979, when 27 per cent and 36 per cent of electric energy are provided by nuclear and coal generation respectively, to the year 2000, when the comparable percentages are projected to be 57 per cent and 21 per cent (Table 8.1).

Public Health. Two aspects of the public health impacts are immediately apparent from the tables in Appendix C. First, the ranges for health impacts on the general public are larger than those for occupational health impacts by two to three orders of magnitude. Second, the differential between fossil- and nuclear-related impacts is also greater for public health impacts than for occupational health impacts, by a factor of 10. These characteristics of the data reflect the great uncertainty of the health impacts associated with atmospheric pollution and nuclear accidents, already mentioned. Because of this uncertainty, it could be misleading to compare scenarios directly on the basis of the public health impacts presented here.

If the mean values of the impact ranges presented really are approximately representative of the true health impacts, then a comparison of scenarios could be justified. If, however, the actual impact of nuclear generation turns out to be close to the upper end of its reported impact range, and the impact of fossil generation near the lower end of its reported range, then we can see from the "General public: equivalent man-days lost" entries in the Appendix C tables that the relative severities of public health impacts of nuclear and fossil generation are reversed for all the scenarios.

When the same comparative technique is applied to the occupational health impacts, the relative severities of nuclear and fossil impacts are reversed for scenarios 1, 2, and 4, while in the other scenarios nuclear and fossil occupational health impacts emerge approximately equal. The results of these different ranking techniques are presented more explicitly in the next section.

Of the five scenarios presented in Table 8.5, scenarios 1 and 4 appear most favourable from a public health standpoint, incurring only a small absolute increase over 1979 levels. These high-nuclear scenarios appear preferable to the medium-growth/high-nuclear scenario because the latter (scenario 2) requires an assumption of some 10,000 GW·h more of fossil-fuelled generation than either scenario 1 or scenario 4. Table 8.6 confirms this, showing an actual decline in per capita public health impact for scenarios 1 and 4. These percentages are mean values of the percentage differences between the high- and low-range values and are therefore based on the assumption that any error in the impact ranges would have the same effect on the fossil impacts as on the nuclear impacts.

Comparison of Scenarios

If it is accepted that the impact ranges for health effects are fairly representative and that actual impacts for fossil and nuclear generation fuel cycles will lie in the same positions within their respective ranges, then Table 8.6 presents as accurate a picture as possible of the relative health impacts of the five scenarios. The high-coal scenarios show overall per capita health impacts increasing by between 65 and 105 per cent. In comparison, the high-nuclear scenarios are by far preferable, showing only a small increase in occupational impacts and an even smaller, or negative, change in public health impacts. This is partly due to the highly expansionary nuclear programme in the "catching up" period which continues through 2000 and slightly beyond. Once nuclear generation reaches the maximum of 70 per cent of total system generation, however, renewed growth in fossil or hydraulic generation can be expected to accompany the high-nuclear scenarios. Per capita health impacts will increase more rapidly once the nuclear "saturation" level has been reached and fossil generation expands at one-half the rate of nuclear generation in order to maintain the 2:1 ratio of nuclear to fossil generation.

By coincidence, scenario 3 represents the case where nuclear generation expands at twice the rate of fossil generation. (Even though it is labelled a high-coal scenario, nuclear generation expands at a greater rate than coal generation because Ontario Hydro has already committed itself to a large

nuclear expansion programme. In all scenarios, we assume that this committed programme will proceed.) Over the 21-year period, per capita health impacts increase by approximately 65 per cent in scenario 3, or by an average of 3 per cent per annum. In scenario 4, the nuclear "saturation" point is reached in the year 2000 or slightly earlier. Assuming the same rate of population growth, the per capita increase in health impacts for scenario 4, beyond the year 2000, can be expected to be approximately 3 per cent per annum or more.

As the highly expansionary nuclear programme slows down and the fossil generation programme resumes a growth pattern, per capita health effects of electric power generation will increase more rapidly than the rates shown in Table 8.6. This is quite understandable, since electric power generation is expanding at a rate two to four times greater than the population growth rate (1.3 per cent per annum). What this means is that the increase in impacts forecast in Table 8.5 is quite low in comparison with the increase that may be expected in the next comparable period, 2000 to 2021, assuming a continuation in the generation mixes and electric power growth rates set forth in these scenarios. The advent of a new generation technology could, of course, change this situation considerably. In sum, the great differences between coal and nuclear scenarios will be somewhat reduced in the period after 2000.

It must also be considered within the realm of possibility that errors in the impact range estimates will have opposite effects on fossil- and nuclear-related impacts. This possibility is explored by assuming that the actual fossil-related impacts are close to the low end of the range given, and that actual nuclear-related impacts are close to the high end of the range. The resulting rankings are presented in Table 8.7. The low-growth scenario remains preferable in both rankings, but, in the medium- and high-growth cases, the high-coal scenarios emerge as preferable to the nuclear scenarios, which is a reversal of the original ranking order.

Table 8.7 Scenario Rankings According to Total Annual Health Impacts: Two Assumptions

	Ranking		
Scenario	Assumption 1[a]	Assumption 2[b]	
1	1	1	Low growth
2	3	3	Medium growth
3	4	2	Medium growth
4	2	5	High growth
5	5	4	High growth

Notes:

a) Assumption 1 is that impact ranges as presented in Table 8.5 and in Appendix C tables are representative of actual impacts, and that any error in these ranges will have the same effect upon nuclear as upon fossil related impacts.

b) Assumption 2 is that actual nuclear related health impacts are closer to the high end of the range reported in Appendix C, while fossil related impacts are closer to the low end of the reported range.

Source: Derived from Table 8.5, of this volume.

The distortion that could arise from ranking scenarios on the basis of these health impact estimates is amply demonstrated: the reinforcing of errors in these uncertain estimates could completely reverse the scenario rankings. It is necessary, therefore, to repeat the warning given at the beginning of this section, that these figures must not be used to rank one energy source or scenario in relation to another. Rather, they serve to enhance our understanding of the effects of a technology deployment.

Additional Considerations Concerning Coal

The great quantities of waste associated in particular with the coal fuel cycle do not represent the only materials-handling problem connected with coal. Of equal immensity is the initial task of transporting millions of tonnes of coal from the mine sites to the generating stations. The quantities of coal delivered to Great Lakes ports in 1977 for consumption at Ontario Hydro generating stations required the full-time commitment in the United States of approximately 500 rail cars with a capacity of 90 tonnes each, travelling an average of 500 km from mine to port, and about 50 similar cars in Canada, travelling some 2,200 km from mine to port. Currently, Ontario Hydro has contracted with three different shipping companies for seven ships to ply the Great Lakes, to complete the transportation link from ports at Ashtabula, Conneaut, and Thunder Bay to the generating stations, all of which are located on or near the Great Lakes and have their own ship-unloading facilities. Four lake freighters transport coal from U.S. ports and three transport coal from Thunder Bay.

Recently, Ontario Hydro together with Canada's two national railways and with mining companies in

Saskatchewan, Alberta, and British Columbia, embarked on a $420 million programme to increase its consumption of western Canadian coal from 200,000 tonnes in 1977 to 3.4 million tonnes by 1980.[12] Major upgrading of tracks and sidings, construction of two lake freighters, expansion of rolling stock to 800 cars, and construction of a new trans-shipment terminal at Thunder Bay will be required, to accommodate this volume of coal freight. In several of the scenarios being hypothesized here, substantial additional coal freight transport would be required. In particular, scenarios 3 and 5, in which, respectively, 68,000 and 83,000 GW·h of electricity are fuelled almost exclusively by coal, were considered from the perspective of coal transport requirements. Oil and gas make up only a small proportion of total fossil generation.

Transportation and the availability of coal must also be seen in an international context. By 1985, U.S. electricity utilities are expected to be using up to twice as much coal as they did in 1978, partly because of the rising cost of oil and the continuing uncertainty about the public acceptability of nuclear power.[13] In order to meet Environmental Protection Agency regulations on sulphur dioxide emissions set out under the 1970 Clean Air Act (U.S.), a great deal of low-sulphur western coal will be imported by many eastern states. This coal will be shipped in part via the Great Lakes. Thirty seven million tonnes of coal were moved on the Great Lakes in 1975, 43 per cent of which was exported from the U.S. to Canada.[14] Ontario Hydro took more than 50 per cent of these imports. U.S. ships and rail carriers haul more coal than any other commodity, and all indications are that the proportion of freight attributable to coal will increase.

These considerations have two implications for Ontario's use of coal to generate electricity. More traffic on Great Lakes waterways could lead to longer turn-around times for freighters if back-ups develop at bottleneck points such as the Welland Canal. Of greater significance, Ontario will be competing with other buyers for the use of delivery systems which, in the case of U.S. railways, are scarcely up to the task of handling existing orders. In 1971, Ontario Hydro leased 75 hopper cars for dedicated service between a mine in West Virginia and the port of Ashtabula, Ohio, to overcome delivery problems stemming from the financial difficulties of eastern U.S. railways and the chronic shortage of rolling stock.[15]

Transportation Requirements: 2000

Table 8.8 sets out the rail and lake freighter requirements in the year 2000 for scenario 3 and scenario 5. The other scenarios are not sufficiently different from 1979, with respect to coal requirements, to warrant separate discussion. It may be seen from this table that, given a 3.5 per cent growth rate for electricity, U.S. rail commitments to Ontario Hydro deliveries would have to be doubled, to 1000 car-years from the current 500. The Canadian rail commitments shown are those now under construction or in operation as a result of the recent expansion programme. Lake freighter years required would increase to nine from the current seven. Greater use of western Canadian coal at the Nanticoke Generating Station is shown to have a significant effect on coal transportation infrastructure requirements (figures in brackets in the table). The use of an additional million tonnes of Canadian coal would reduce U.S. rail requirements by 60 car-years, but it would increase the Canadian car-years required by 300, due to the far greater distances involved. Also, one additional lake freighter would be required.

Table 8.8 Transportation of Coal: Infrastructure Requirements in the Year 2000

	Assumed distrib'n of gen. GW·h	Fuel required (t × 10⁶) per year		Lake freighter yrs. req'd.	Rail car yrs. required		Assumed distrib'n of gen. GW·h	Fuel required (t × 10⁶) per year		Lake freighter yrs. req'd.	Rail car yrs. required	
Location		U.S.	Can.		U.S.	Can.		U.S.	Can.		U.S.	Can.
St. Lawrence R.							10,000	3.2	2.5	200		
Lake Ontario	29,000[a]	8.0		3.8	500		24,000	7.7		3.7	480	
Lake Erie[b]	20,000	4.5	2.5	4	280	670	20,000	4.5	2.5	4	280	660
		(3.5)[b]	(3.5)	(5)	(220)	(930)		(3.5)	(3.5)	(5)	(220)	(920)
Lake St. Clair	11,000	3.5		1.4	220		11,000	3.5		1.4	220	
Lake Huron							10,000		3.8	1.6		1,000
West System	8,000		6.3[c]			130	8,000		6.3[c]			130
Total	68,000	16	8.8	9.2	1,000	800	83,000	18.9	12.6	13.2	1,180	1,790
		(15)	(9.8)	(10.2)	(940)	(1,060)		(17.9)	(13.6)	(14.2)	1,120	(2,050)

Notes:
t = tonnes

a) Includes 6,500 GW•h co-generation.
b) There are two variations for Lake Erie. The first variation assumes 2.5 million tonnes of western Canadian coal is used in fuelling Nanticoke G.S. The second variation, shown in brackets opposite the Lake Erie entry and below the first variation, assumes one half of Nanticoke fuel, (3.5 million tonnes) consists of western Canadian coal. All figures in brackets indicate the corresponding values for the second variation.
c) Consists of 0.9 million tonnes Saskatchewan lignite and 5.4 million tonnes Onakawana lignite.
Source: Derived from information provided by Ontario Hydro Fuels Division. See also Appendix D.

If electricity demand grows at 4.5 per cent per annum and Ontario opts for significant expansion of fossil generation, Canadian rail-car requirements could increase by 250 per cent to some 2,000 car-years, and freighter requirements could double between 1979 and 2000. U.S. rail requirements would increase somewhat over those projected for 3.5 per cent electricity demand growth. Also in scenario 5, the Thunder Bay trans-shipment terminal would have to be expanded beyond its 5.4 million tonnes capacity, or supplemented, since 7-8 million tonnes of coal would be trans-loaded annually from rail cars to freighters.

Furthermore, it is quite conceivable that supplies of western Canadian coal to Ontario Hydro will increase even more than is shown in Table 8.8 and that dependence on U.S. coal will diminish correspondingly, for two reasons. The increasing domestic demand for U.S. coal has already been noted. This demand could, at least in the short to medium term, make it difficult for Ontario to procure U.S. coal until mining and transportation infrastructure have been sufficiently expanded to meet the rising demand. In other words, there could be a temporary supply shortage of U.S. coal if domestic demand increases too rapidly. Secondly, the increasing Canadian and international concern about acid rain and sulphur dioxide emissions could well result in more stringent emission guidelines, as has already been pointed out. Undoubtedly, Ontario Hydro will find, as eastern U.S. utilities have, that the use of low-sulphur western coal is a more cost-effective way to reduce sulphur emissions than the installation of expensive emission control equipment. For these reasons, the requirements for expansion of the coal transportation system presented here could well prove conservative.

In summary, infrastructure requirements for the transport of coal could increase dramatically with increasing coal-fired generation and a shift from U.S. to Canadian coal. Major problems could occur if the rail freight system was unable to expand sufficiently, creating difficulties similar to those chronically experienced in the delivery of Canada's wheat to ports of export.

Environmental and Health Effects of Using More Canadian Coal

In addition to straining delivery systems, the use of more western Canadian coal instead of U.S. coal in Ontario's generating stations will have effects on the environmental and health impacts of electric power, because of the different characteristics of the two fuels, and the different transport distances. Each coal deposit is characterized by its own unique properties. Of particular interest are the energy content of the coal and the percentage of sulphur and ash it contains. Table 8.9 sets out these characteristics for the various coals used by Ontario Hydro. Part B of the table standardizes the sulphur and ash contents on the basis of equal energy output, and from this it may be seen that, for each unit of energy generated, western Canadian coal emits only 25 per cent as much sulphur as eastern U.S. coal, but almost twice as much ash. The reduction of sulphur loadings that can be achieved by substituting western Canadian coal for eastern U.S. coal, therefore, also means an increase in ash deposits.

Table 8.9 Characteristics of Coal Burned by Ontario Hydro

	Sulphur	Ash	Heat content/tonne
A. Approximate sulphur and ash contents			
U.S. bituminous coal	2.4%	10%	3.1 MW•h
W. Canada bituminous coal	0.5%	15%	2.6 MW•h
Saskatchewan lignite	0.6%	8%	1.7 MW•h
Onakawana lignite	0.5%	11.3%	1.2 MW•h
B. Standardized sulphur and ash contents			
U.S. bituminous coal	1.00	1.0	1.0
W. Canada bituminous coal	0.25	1.8	1.0
Saskatchewan lignite	0.45	1.4	1.0
Onakawana lignite	0.55	3.0	1.0

Source: Ontario Hydro Fuels Division, 1979.

This situation leaves the decision-maker in a quandary, due to the incomplete understanding of the

synergistic effects of sulphur and particulate emissions in flue gases, and the resulting health effects. It is not entirely clear whether it is preferable, from a public health perspective, to reduce sulphur emissions or particulate emissions. From an environmental perspective, however, it is clearly preferable to burn low-sulphur coal, since it is easier and less costly to control fly ash emissions than sulphur emissions. Environmental impacts estimated in Tables 8.2 and 8.3 are based on the burning of U.S. coal. If the proportion of Canadian coal burned by Ontario Hydro were to be increased to 50 per cent, the sulphur loadings estimated would decrease by some 30 per cent, while the amount of ash generated and land required for ash disposal would increase by approximately 40 per cent.

No attempt will be made here to estimate the change in health impact on the general public that might result from the increased use of low-sulphur coal, for such an estimate would have little scientific substantiation and would only further complicate an already confused picture. But there is one change in the health impact that would result from the increased use of western Canadian coal that can be computed. It is estimated that two fatalities and 1-20 disabilities are incurred by transporting 2.2 million tonnes of coal 500 km. On that basis, for each million tonnes of coal transported an additional 1,500 km to bring it from western Canada rather than from U.S. coalfields closer to Ontario, an additional 1.4-27 disabilities would be incurred. Furthermore, these transportation-related impacts on health and the environment shift to Canada from the U.S.

Summary and Discussion

Heeding our own advice, we turn away from any further attempts at ranking, and conclude with an overview of some of the trade-offs faced by decision-makers under varying conditions of growth in demand for electric power. While the focus will be on the trade-offs related to health and environmental effects, it must be remembered that the three electricity demand growth rates discussed are not the only options available. One of the most fundamental choices available to the people and government of Ontario concerns the extent to which they will exert control over the growth in demand for energy. The discussion of the impacts of conservation has not been taken up here. Nevertheless, it is most evident from the data presented in this volume, that even at current rates of energy consumption, and specifically of electric energy consumption, considerable health and environmental impacts are incurred both within Ontario and elsewhere. Consumption of less energy can play an important part in the short to medium term, by buying time during which at least some of the remaining technical problems can be solved, the social or economic dislocations overcome, and the level of understanding of the issues raised. In particular, the technical problems of nuclear waste management need further attention, the change to more costly energy and different sources of energy must be accommodated, and our understanding of the health effects and the risk assessment of energy systems requires significant refinement.

No wholly benign choices are available, although some options are undoubtedly preferable to others. Of course, as soon as preferences enter the picture, a broad range of social and political issues comes into play. How does one choose among dissenting preferences or determine the limits of acceptability of impacts and risks? These are important questions for the decision-maker, for it is upon them that the factual evidence must be brought to bear. That is why this chapter ends with a brief discussion of the interpretation of impacts and risks. Chapter 9 introduces and discusses the regulation of health and environmental impacts, considering the provincial, federal, and international standards and the monitoring and enforcement mechanisms that are relevant to energy systems and fuel cycles.

Three Growth Rates

At the outset, it was stated that low, medium, and high growth rates of Ontario's electric power demand to the year 2000 may be expected to approximate 2.5 per cent, 3.5 per cent, and 4.5 per cent, respectively. The salient features of Ontario's options in each case will be reviewed briefly.

At the 2.5 per cent rate of growth in electricity demand, there are virtually no options available to Ontario, since all of the generation capacity needed to supply this demand is either already built or is part of Ontario Hydro's "committed programme". At the low growth rate (2.5 per cent per annum), impacts from fossil generation are projected to be much the same in 2000 as in 1979, since all growth in electric power demand is met by existing or committed nuclear plants. Impacts related to nuclear electricity generation will be the same as those identified for scenario 3, since in both scenario 1 and scenario 3 the nuclear programme is projected to expand in accordance with the "committed programme", and no further, by the year 2000.

The most significant land-use requirement for the low growth rate consists of 25 km^2 needed for ash disposal, most of which would be located in southwestern Ontario where, in the year 2000, over 50 per cent of coal-fired generation will be situated. At this growth rate, it is not anticipated that the Onakawana lignite deposits will be developed for electricity generation. Cooling water requirements and thermal water releases will increase by some 250 per cent to approximately 72×10^9 litres per day, and 27,000 megawatt years per year, respectively. Releases of tritium and other radiation to both water and air will double, and the quantities of nuclear waste being handled annually will increase to 350 per cent of the 1979 volumes by the year 2000. From Table 8.5, we can determine that, for the low growth rate, occupational impacts in the year 2000 are expected to increase as follows:

Fatalities: a 12-24 per cent increase over those of 1979;

Disabilities: a 20-30 per cent increase over those of 1979. Public health impacts are expected to change much less, fatalities increasing by approximately 1 per cent and equivalent man-days lost by approximately 8 per cent over 1979 levels by the year 2000. On a per capita basis, however (Table 8.6), health impacts for scenario 1 actually show a decline of some 15 per cent from 1979 levels.

As electricity demand growth rates increase to 3.5 per cent and 4.5 per cent, options for varying the coal:nuclear generation mix, and thereby for making certain trade-offs among environmental and health impacts, expand. Land requirements in the year 2000 are 40 per cent (15 km^2) greater for the high-coal scenario than for the high-nuclear scenario (Table 8.2) in the medium-growth case, and this difference increases to 150 per cent in the high-growth case. Over the 21-year period 1979-2000, cumulative land requirements differ by 50 km^2 and 190 km^2 (Table 8.3) for the medium and high growth rates, respectively, the high-nuclear scenarios (2 and 4) requiring less land in both cases. Land requirements for nuclear waste disposal and plant decommissioning are not included in these figures, and it should not be forgotten that land for these purposes will be pre-empted from other uses for a much longer period than land used for ash disposal.

The major water impacts have been identified as water usage, thermal releases, radioactive releases, and acid drainage (Tables 8.2 and 8.3). In both the medium-growth and high-growth cases, annual water usage and thermal releases are approximately 10 per cent higher in the year 2000 for the high-nuclear scenarios than for the high-coal scenarios. Radioactive releases, however, are expected to be 15 per cent and 40 per cent greater in the high-nuclear scenarios than in the high-coal scenarios. On the other hand, acid drainage is 50 per cent greater for the high-coal scenario than for the high- nuclear scenario in the medium-growth case and 250 per cent greater in the high-growth case. Insofar as water impacts are concerned, then, there appears to be a possible trade-off between acid drainage and radioactive releases. It should also be remembered that a large portion of the acid drainage from coal mines and coal- storage facilities will occur outside Ontario.

In the realm of air impacts, scenarios 3 and 5 produce 50 per cent more fly ash, sulphur dioxide, carbon dioxide, nitrogen oxides, and trace metals by the year 2000 than do their high-nuclear counterparts, scenarios 2 and 4, respectively. These effluents are expected to become a problem, unless they are controlled in the near future. It must be remembered, however, that control mechanisms for sulphur dioxide and fly ash are readily available. Furthermore, the use of western Canadian coal instead of U.S. coal could reduce sulphur dioxide emissions by 30 per cent or more. The levels of radioactive releases to the atmosphere that are projected for all scenarios, under normal operation, do not present any difficulties.

Table 8.10 highlights the environmental impacts associated with the various scenarios and injects a qualitative assessment of the overall impacts through the use of low, medium, high, and very high ratings. These ratings are highly subjective, but they do reflect at least to some extent the tentative directions and conclusions arrived at in previous chapters.

Enough has been said about the comparative health impacts of the five scenarios that a recapitulation here is not necessary. Two critical points are worth repeating, however. The serious uncertainty about the health impacts of the coal-electric fuel cycle has to do with the effect of atmospheric emissions, during normal operation, on the incidence among the public of bronchial and asthmatic illness and induced mortality. By contrast, the uncertainty about the nuclear-electric fuel cycle concerns the likelihood of a major accidental release of radiation and the extent of the resulting health effects. The decision-maker is faced with weighing these alternative risks in the context of a very limited understanding of each. The interpretation of these risks is discussed briefly in the next section.

Table 8.10 Overview of Annual Environmental Impacts of Electricity Generation Scenarios in the year 2000

	Low-growth scenario	Medium-growth scenarios		High-growth scenarios	
Impact	1	2	3	4	5
Land use	Low Only very small increases over 1979 levels of land use, for mining, milling, and tailings disposal.	Medium Annual increase of 40 within Ontario over 1979 levels. Primarily landfill in southern Ontario.	Medium Higher than for Scenario 1, 100% annual increase over 1979 requirements.	Low Almost identical to Scenario 1 annual requirements.	High Two to three times 1979 annual requirements. Mostly landfill in southern Ontario, but also mine-site at Onakawana.
Water	Medium 200 to 250% increase in radiation release and water usage over 1979 levels.	High Slightly higher than Scenario 1 for all impacts except acid drainage, which increases 30%.	High As for Scenario 1, plus increase in acid drainage of 100% over 1979 levels.	Very high Fourfold increase in cooling water, thermal discharge and radiation releases over 1979. No change in acid drainage.	Very high As for Scenario 4, but somewhat lower radiation releases and 250 more acid drainage.
Air	Low Doubling or radio active emissions over 1979 levels, under normal operating conditions.	Medium Major concern is with fossil generation releases and nuclear accidental releases. Slight (30%) increase over 1979 levels of SO_2, CO_2 and NO_x, assuming no new controls.	High 100% increase in fossil stack releases over 1979, assuming no new controls.	Medium Fossil stack releases as for 1979, and threefold increase in radioactive releases.	Very high 150% increase in fossil generation stack releases.

Source: Based on Table 8.2, this volume, and the accompanying discussion.

The Interpretation of Risk

In general terms, risk may be thought of as a potential for the occurrence of unwanted, negative consequences.[16] A closer look reveals further attributes of risk. A risk may be voluntary or involuntary. Voluntary risks imply that the risk-taker has an acceptable alternative available to him and can thereby avoid taking the risk. Any risk about which information is purposely withheld is automatically involuntary. Risks may also be described as equitable or inequitable. This takes into consideration the distribution of risks and benefits. If the person who takes the risk also reaps the benefit, then it is an equitable risk. Finally, one can think of risks as lying somewhere on a continuum from common to catastrophic. Common risks are taken frequently, such as the risk of crossing the street or riding in a bus. In fact, everybody takes risks of many kinds in every day of normal activity. The important factor is that these common risks are acceptable to the individual taking them. Generally speaking, unacceptable risks tend to be involuntary, inequitable, and of a catastrophic or near-catastrophic nature. That is not to say that this must always be so. For example, most people would agree that smoke inhalation from other people's cigarettes is, in most cases, a nuisance that could be considered a common risk. Recently imposed anti-smoking legislation and the surrounding controversy has amply demonstrated that this involuntary, inequitable, but common risk is, in fact, not acceptable.

The distribution of risks in space and time is also of importance in judging the significance of a risk in relation to the magnitude of its consequences. For example, automobile accident fatalities are frequent and therefore common, and amount to relatively high numbers in the course of one year, perhaps many thousands, depending on the area considered. These deaths are considered common and usually acceptable, and yet an air crash, involving perhaps several hundred deaths, is considered catastrophic because it occurs at one point in space and time. It is generally agreed that risks that have a high frequency of occurrence, that are widely distributed over society, and that have a relatively low consequence are more readily accepted than risks that occur infrequently, focus on a specific region or individual, and are characterized by high consequences (e.g., many simultaneous deaths or disabilities).

In essence, the difference between risk estimation and risk evaluation is that risk evaluation goes beyond the strictly numeric calculation of risk consequences and probabilities; it includes also a qualitative consideration of the way in which risks are perceived. Consider what this means for the risk

estimates provided in this report. Table 8.11 attempts to describe the major involuntary risks or impacts associated with the coal and nuclear fuel cycles in terms of the characteristics noted above. The first column describes the risk in terms of both its spatial distribution and whether or not the benefit/risk allocation is equitable or inequitable. It was generally considered that if risk-takers reaped a benefit (e.g., electric power or economic gain) then the risk was equitably distributed, unless it was clearly out of proportion with the benefit, as in the case of a nuclear waste disposal site that could store all the waste from an entire regional generation programme for many decades to come. Considering the longevity of radioactivity in tailings, an argument could be made that the risk of water pollution from tailings is inequitable, even though the economic benefit from the mining operation accrues to the same general area where the tailings are situated.

Table 8.11 Characteristics of the Major Involuntary Impacts/Risks of the Coal and Nuclear Fuel Cycles

Impact/Risk	Distribution	Frequency	Consequence	Consequence reversibility	Public concern
Coal					
Water pollution from acid drainage	local and regional (equitable)	low	low	high	low
Water pollution from acid rain	regional and global (inequitable)	low	high	low	high
Property damage from dust in air	local and regional (equitable)	medium	low	high	low
Health impact from generation emissions	regional and global (inequitable)	high	unknown but probably medium	low	low
Climatic change from CO_2 emissions	global (inequitable)	very low	unknown but could be very high	low	low
Nuclear					
Water pollution from radioisotopes					
–tailing drainage	local (equitable)	high	medium	medium	low
–cooling water release	local and regional (equitable)	high	low	high	low
–solid waste disposal drainage	local and regional (inequitable)	low	high	medium	high
Contamination from accidental release of radioisotopes to atmosphere	local and regional (equitable)	low	varies with exposure could be very high	low	high

Source: Based on Chapters 2, 4, and 8 this volume, and author's subjective assessment.

The second and third columns in Table 8.11 describe the temporal frequency and magnitude of the consequence of each risk. The fourth column introduces a new variable that is usually applied only to environmental risks, but is also useful when considering health risks. The degree of reversibility of an impact is of great importance in determining its significance. For example, a fish kill of 1,000 trout is noteworthy, but not catastrophic. In contrast, a kill of 10 bald eagles could have an irreversible consequence – extinction of the species. The last column presents a rough assessment of current Canadian public concern about the risk.

The technical risk-assessor would focus his attention on the "frequency", "consequence", and "consequence reversibility" columns to determine the relative significance of each risk. Following this approach, the most significant risks, in descending order, would probably emerge as: health impact from coal generation, water pollution from tailings, acid rain pollution, contamination from accidental radiation releases, and climatic effects of carbon dioxide emissions. This listing coincides only haphazardly with the issues of high public concern. One explanation is that public perception focuses primarily on the nature of the consequence, eschewing the more complicated probability formulae that incorporate other variables. The known, high-consequence, involuntary risks therefore also usually appear high on the list of public concerns. The degree of general knowledge about a risk and its consequences is, of course, also an important factor in determining its acceptability. As more knowledge about other risks, such as carbon dioxide buildup in the atmosphere, becomes widely available, the acceptability of these risks may well change. Education is therefore a key element in any risk management programme.

The public's mistrust of probability figures and numerical risk factors was indicated in an article on the subject in *Maclean's* magazine:

> In public hearings such as the one in Ontario, for every scientific allegation, whether pro- or anti-nuclear, there is a scientific rebuttal. Who can be believed? While scientists and technologists talk in terms of million- or billion-to-one odds against any particular disaster, the engine has fallen from the wing of a DC-10 in flight; an oil well has blown on the bed of the Gulf of Mexico and continues – uncontrollably – to spew 30,000 barrels a day into the sea; Skylab has crashed to earth almost completely out of control of its technological creators. With precedents like these, with such "worst possible scenarios" occurring regularly along the frontiers of technology, it is no wonder that the public is uneasy, resentful and distrusting of the nuclear industry. Its continuing reliance on the philosophy of *technofix* – as technology creates problems, technology will find a way to solve them – doesn't reassure the way it used to.[17]

To sum up, the collection of great amounts of data and the evaluation of the technical and economic aspects of modern life are essential, partly to allow us to determine which efforts at reducing risk do not in turn incur greater risks than the reduction achieved. Great efforts are still needed in this technical area. Furthermore, a full evaluation of risk in the decision-making process involves the interface between so-called "hard" sciences and technologies and the "soft" political and social sciences. The marriage is far from being consummated, for there are still large discrepancies between formal evaluations of risks and the public perceptions of those risks.

CHAPTER NINE

The Regulation of Environmental and Health Impacts from Energy Systems

The management, or control, of risks, or the negative impacts of technology, is undertaken by international regulatory bodies such as the International Commission on Radiological Protection (ICRP) as well as by federal and provincial governments in Canada. Risk management tools include policies such as marketing incentives (e.g., emission taxes and pollution control capital write-off inducements), the setting of regulations (standards, criteria, and guidelines), and direct intervention through the imposition of bans or control orders. The most common approach is regulation by imposing standards and guidelines based on scientifically established criteria of tolerance and politically established levels of acceptability. The power of direct intervention is usually reserved for dangerous violations of established regulations and for emergency situations.

Chapters 1-8 of this volume presented the various environmental and health effects of the different electric energy technologies and the related fuel cycles. Emphasis was given to the uranium-electric and coal-electric systems, because these were seen to constitute Ontario's major bulk power options until the year 2000. Impacts from oil-fired generation are very similar to those from coal-fired generation; hydraulic, solar, and wind generation incur health and environmental impacts primarily in the construction phases.

Major construction projects in Ontario are, or shortly will be, subject to approval under the Environmental Assessment Act, 1975. The provisions of this act and its workings are described in Volume 8 of this Report. Briefly, the act requires proponents of an undertaking to prepare a report describing the project, identifying in detail the environmental impacts the project will have, and indicating the measures planned to control these impacts within acceptable levels. If construction-related impacts are found to be excessive, additional controls may be imposed or approval withheld. In this manner, impacts from the construction of pipelines, dams, refineries, and new installations such as solar photovoltaic plants will be monitored and controlled. Each construction project will have different related impacts depending on the construction techniques used, the location, and the time of year. It is not possible here to consider in detail the regulations that apply, since this would involve a review of virtually all current environmental and health regulations and procedures applicable in Ontario. However, the environmental assessment procedure, which encourages public participation, is a comprehensive mechanism capable of ensuring environmental quality control of the same calibre that is gaining increasing acceptance elsewhere in North America and in Europe.[1] The critical qualification, of course, is that all projects with significant impacts are designated as being subject to this act.

Apart from construction-related impacts, the major health and environmental effects of electric power generation in Ontario have been found to be associated with the coal-electric and uranium-electric cycles. The major pollutants of concern have been identified as follows:

1. Related to the coal-electric generation system:
Mining – acid drainage
Transportation – dust, sediment
Generation – flue-gas constituents (carbon dioxide, sulphur dioxide, nitrogen oxides, hydrocarbons, suspended particulates, ozone), waste heat
Waste disposal – acidic leachate

2. Related to the uranium-electric generation system:
Mining and milling – acid drainage, ammonia, nitrates, dissolved solids, thorium, radium, heavy metals, dust, suspended particulates, radon gas
Refining – waste heat, nitrates, uranium, sulphur dioxide, ammonia, nitrogen oxides, fluorine
Heavy water production – hydrogen sulphide
Generation – waste heat, radioisotopes (noble gases, iodine-131), tritium
Waste disposal – radioisotopes, radium, acidic leachate

In this chapter, standards, objectives, and criteria that have been applied to these pollutants, and related enforcement mechanisms, are presented and discussed, in order to provide a perspective on the regulation of environmental quality in Ontario.

Standards, Objectives, and Criteria

Before setting out the actual effluent limits or environmental quality indicators prescribed by law, regulation, or practice, it is important to understand these three terms, and how they are used.

Standard. A standard is a regulatory limit, usually set out in regulations made under an act of Parliament or the Legislature such as the Clean Air Act (Canada) or the Environmental Protection Act (Ontario). Standards are usually expressed as allowable concentrations of a contaminant per unit of effluent or per unit of air or water, depending on the approach taken and the purpose of the standard.

Objective. An environmental quality objective is a statement of the goals of air-, land-, or water-use management that stipulates the desired uses of the environment and the general level of quality required to sustain that use. For example, a statement that water quality in Lake Ontario should be such as to sustain sports fish for human consumption and to allow swimming would be a general water-quality objective. Specific environmental quality objectives that provide quantitative descriptions of allowable concentrations of specific physical and chemical parameters that will not interfere with a particular use are also found in Canada. Thus, a requirement that the dissolved oxygen level in water at 20°C be at least 5 milligrams per litre to sustain healthy aquatic life is an example of a specific water-quality objective.

Criterion. A criterion is the highest (or lowest) level of a substance in air, land, or water which, on the basis of experimental evidence, produces no measurable detrimental effect on biological life. While criteria may be considered statements of scientific fact, it is important to recognize that there is always an element of uncertainty and subjectivity associated with such statements, resulting from differences in experimental findings and data interpretations. Nevertheless, criteria are the bases upon which specific environmental quality objectives are formulated.

Elements of subjectivity enter into environmental quality objectives in several ways. Value judgements are involved in determining the uses of the air, land, or water that are desirable and must be protected. Subjective aspects of the criteria upon which objectives are based have already been mentioned. Finally, the manner in which environmental quality is to be sampled and determined frequently involves some technical subjectivity. Where objectives are written into regulation form to become standards, these elements of subjectivity apply equally. This is acceptable so long as it is recognized that standards and objectives reflect social and political values, as well as scientific fact. The major implication here is that the discussion on the setting of standards and objectives must not be confined to experts and special interest groups, but must include the widest range of the population making use of the environment that is to be regulated.

A final consideration when interpreting standards, objectives, and criteria is that only measurable concentrations of contaminants can be regulated. Hence, the effects of minute, unmeasurable quantities of a contaminant are extremely difficult to determine and in any event cannot be controlled. This is of particular relevance to pesticides for which criteria tend to be adjusted for analytical constraints.[2]

Air Management

Federal. Air quality in Ontario is regulated by both federal and provincial levels of government. Federal regulations, made under the Clean Air Act, 1971, specify tolerable, acceptable, and desirable levels of air quality for specific contaminants (see Table 9.1). The maximum desirable level represents the long-term goal for air quality while the maximum acceptable level is deemed to provide adequate protection against negative effects on the biological and physical environment and on human health and comfort. The maximum tolerable level is intended as an indicator of imminent danger to the prevailing life-style or to public health, requiring immediate abatement action. These air-quality objectives are not legally enforceable and act primarily as bench-mark references for provincial governments in setting air-quality standards so that provincial requirements are at least as stringent as the federal "acceptable" objectives. It may be seen from Table 9.1 that Ontario's criteria follow this pattern.

Table 9.1 Ambient Air Quality Standards and Criteria for Ontario, Canadian Air Quality Objectives, and Ambient Air Quality Standards for California and the United States

Parameter	Time period	Unit of measurement	Ontario	Canada			California	United States	
				desirable	acceptable	tolerable		primary	secondary
CO	1/2 hour	ug/m^3 [a]	6,000	–	–	–	–	–	–
–	1 hour	ug/m^3	36,200	15,700	37,400	–	48,300	40,000	40,000
–	8 hours	ug/m^3	15,700	6,050	15,700	20,500	12,100[b]	10,000	10,000
H_2S	1 hour	ug/m^3	30	–	–	–	–	–	–
NH_3	1/2 hour	ug/m^3	3,600	–	–	–	–	–	–
NO_2	1/2 hour	ug/m^3	500	–	–	–	–	–	–
–	1 hour	ug/m^3	400	–	420	1,060	500	–	–
–	24 hours	ug/m^3	200	–	220	320	–	–	–
–	1 year	ug/m^3	–	60	100	–	–	100	100
Ozone	1/2 hour	ug/m^3	200	–	–	–	–	–	–
–	1 hour	ug/m^3	165	103	165	309	206	235	235
–	24 hours	ug/m^3	–	30	52	–	–	–	–
–	1 year	ug/m^3	–	–	30	–	–	–	–
SO_2	1/2 hour	ug/m^3	830	–	–	–	–	–	–
–	1 hour	ug/m^3	690	470	940	–	1,300	–	1,300[c]
–	24 hours	ug/m^3	275	165	305	855	110	365	–
–	1 year	ug/m^3	55	30	55	–	–	80	–
SPM	1/2 hour	ug/m^3	100	–	–	–	–	–	–
–	24 hours	ug/m^3	120	–	120	400	100	260	150
–	1 year	ug/m^3	60	60	70	–	60	75	60
Dustfall	30 days	tonnes/km^2	7	–	–	–	–	–	–
–	1 year	tonnes/km^2	55	–	–	–	–	–	–
–	1/2 hour	ug/m^2	8,000	–	–	–	–	–	–

Notes:

Dash (–) in column denotes standard not set.

a) ug/m^3 measured at 10°C and 760 mm Hg pressure.

b) 12-hour limit.

c) 3-hour limit.

Sources:

1. "The Environmental Protection Act" (Ontario, 1971).
2. "Clean Air Act Annual Report", 1977-8, Environment Canada.
3. A.C. Stern, "Air Pollution", Volume 5, 3rd edition, 1977; 4. EPS data from "Identification, Assessment and Regulation of Toxic Air Pollutants" by J.D. Bachmann and J.R. O'Connor, EPA, Office of Air Quality Planning and Standards.

Table 9.2 Water Quality Objectives for Ontario and Canada, and Water Quality Standards for Michigan, California, and the United States [a]

Parameter	Ontario	Canada	Michigan	California	United States
Dissolved solids	Must not be added to increase the ambient concentration by more than 33% of the natural concentration to protect aquatic life. The solids should not significantly alter the overall ionic balance of the receiving waters.	–	NA	NA	Also known as salinity, maximum of 250 mg/L of total chlorides and sulphates (drinking water)
Suspended matter	Should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10 %; all waters shall be free from substance attributable to man-caused point or non-point source discharge in concentrations that produce objectionable colour, odour, taste, or turbidity.	–	No objectionable, unnatural turbidity, colour, or deposits sufficient to interfere with the designated uses.	–	Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonably established norm for aquatic life.
pH	6.5–8.5		Public water supply and agricultural: no variation of more than 0.5 pH unit from natural; all other uses 6.5–8.8.	6.5–9.5 range for various lakes, rivers, and bays; however, most standards fall into the 7.0–8.5 range.	6.5–9.0
Temperature	Natural ambient water temperature not to be exceeded by more than 10°C (18°F). Maximum temperature of receiving water outside of mixing zone must be less than 30°C (86°F)	Objectives/ guidelines are industry-specific.	Public water supply: 10°F allowable rise above natural temperatures. Industrial: same as pws. Recreation: 90°F maximum Fish and wildlife: cold water fish 70°F maximum 10°F change limit Navigation: same as pws.	Cold interstate waters-ETWs. prohibited Warm interstate waters-TWs greater than 5°F above receiving water temperature prohibited; ETWs shall not raise receiving water temperature by more than 5°F. (Standards are much more extensive – refer to source. TW–thermal waste ETW–elevated temperature waste)	Maximum temperature 90° with a maximum permissible rise of 5°F above natural temperature of streams and 3°F in lakes. Trout and salmon waters not to be warmed in order to protect these resources.
H_2S	Concentration of undis-sociated H_2S should not H_2S should not exceed 2 ug/L at any time or place to protect aquatic life.	–	2 ug/L undissociated H_2S for the protection of aquatic life.		2 ug/L undissociated H_2S for the protection of aquatic life.

Table 9.2 Water Quality Objectives for Ontario and Canada, and Water Quality Standards for Michigan, California, and the United States[a] (continued)

Parameter	Ontario	Canada	Michigan	California	United States
Heavy Metals					
vanadium	–	–	–	–	–
zinc	30 ug/L[e]	200-500 ug/L	0.01 of $96_{HR}LC_{50}$[g]	100 ug/L	5,000 ug/L
cadmium	0.2 ug/L[e]	–	0.4–12.0 ug/L[i]	0.01 ug/L	10 ug/L[h]
iron	300 ug/L[e]	–	1,000 ug/L[g]	–	1,000 ug/L[g]
mercury	0.2 ug/L[f]	–	0.01 ug/L[g]	–	0.05 ug/L[g]
selenium[c]	10 ug/L	–	0.01 of $96_{HR}LC_{50}$[g]	–	0.01 of $96_{HR}LC_{50}$[g]
Salinity[d]	3,000 mg/L	–	–	–	–

Notes:

a) The time interval is not set for the standards show in this table.

b) California issues its standards according to regional jurisdictions and thus specific areas are covered (36 regions to date).

c) Drinking-water criteria.

d) Criteria for livestock watering.

e) Expressed in concentrations in an unfiltered sample.

f) Expressed in concentrations in a filtered sample.

g) Aquatic (Michigan) or fresh-water aquatic life (EPA) standards.

h) Drinking-water standards.

i) Cadmium standards
soft waters: 0.4 ug/L – cold-water fish; 4.0 ug/L – warm-water fish.
hard waters: 1.2 ug/L – cold-water fish; 12.0 ug/L – warm-water fish.

Sources:

"Water Management", Toronto: Ministry of the Environment, 1978. "Metal Mining Liquid Effluent Regulations and Guidelines", Fisheries and Environment Canada, 1977, Environmental Protection Service. "Water Quality Standards Criteria Digest: A compilation of Federal and State Criteria", Washington, D.C.: Environment Protection Service, 1972. Communication with EPA, A ugust 1979, material quoted from EPA's " Quality Criteria for Water" (The Red Book) 1977, and a draft of Michigan's standards dated March 1977.

Under section 8 of the Clean Air Act, national emission guidelines have been set for several industries, including arctic mining operations. Similar guidelines are under development for the natural gas processing, thermal power generating, and petroleum refining industries. These guidelines are only enforceable where they apply to works involving the federal government, but are intended as objectives for other operators.

National emission standards to protect public health can also be prescribed under section 7 of the Clean Air Act, but no standards have been set for the contaminants that concern us here. Of greater importance, section 7 provides for the setting of air-emission standards to ensure compliance with the terms of any international obligation entered into by the Government of Canada. Any agreements resulting from impending negotiations with U.S. authorities on control of trans-boundary atmospheric pollution, particularly sulphur dioxide and nitrogen oxides, could therefore be directly implemented and enforced through existing legislation, assuming that such agreements take the form of emission controls. Similarly, the U.S. Clean Air Act provides for modification of state implementation plans to take account of endangerment of public health and welfare in a foreign country, provided that reciprocal arrangements exist with that country. It is to be expected, therefore, that increased controls on U.S. sources of sulphur dioxide and nitrogen oxide emissions will have to be accompanied by similar controls in Ontario, since our emissions periodically contribute to acid rain in New York and the New England states.

Provincial. The Province of Ontario sets ambient air-quality criteria in regulations made under the Environmental Protection Act, 1971 (Table 9.1). Criteria are designed to provide an ambient air quality that precludes any known adverse effects. Emission allowances are derived from ambient air-quality criteria using specified formulae relating the location, velocity, and dispersion of the emission to the nearest point of impingement on people, animals, vegetation, or property. A conventional source emission number is therefore not given, since each emission source will vary in its characteristics and will therefore have its own unique allowable emission factor. The major difficulty with this "philosophy of effects" approach is the incentive it provides to disperse contaminant emissions rather than reduce them. The best example is the International Nickel Company superstack at Sudbury, which reduced the negative effects to Ontario of sulphur emissions, but transported these effects to Quebec, the Maritimes, and the northeastern U.S., beyond the jurisdiction of the regulating authorities. Dilution is clearly not the solution to pollution, and both ambient quality and total contaminant emissions must be regulated.

As part of its air management programme, the Ontario Ministry of the Environment has developed an

air pollution index (API) and alert system, pursuant to regulation 15 under the Environmental Protection Act. This index is computed on the basis of sulphur dioxide concentrations and "coefficient of haze" (suspended particulates) readings and is given for the major cities and industrialized centres of the province. The alert system functions at four levels: 32 (advisory level), 50 (first alert), 75 (second alert), and 100 (air-pollution episode threshold level). At an API reading of 32, if meteorological conditions indicate that poor dispersion conditions are to continue for at least six hours, major air polluters are requested to cut back on emissions. At an API of 50 or more, these operators may be ordered to curtail operations. At the 100 reading, the Minister of the Environment can order closure of all operations contributing to air pollution and not essential to public health and safety. Ash and suspended particulate emissions may also be controlled through the regulation of opacity of visible emissions. Regulations limiting to 1.5 per cent the sulphur content of No. 6 fuel oil and of bituminous coal, both of which are used by Ontario Hydro, are in effect only in the Municipality of Metropolitan Toronto.

Water Management

Federal. Table 9.2 sets out water-quality objectives for Ontario, Canada, and several jurisdictions in the U.S. The lack of entries for Canada indicates that the federal approach is not to regulate ambient water quality. Rather, federal guidelines set allowable emission concentrations for industry-specific contaminants (see Table 9.3). Combined with the provincial water-quality objectives which regulate ambient water quality, this affords the province the advantage of both types of control. Federal emission guidelines apply only to a very few industries to date, however.

Table 9.3 Metal Mining Liquid Effluent Regulations, Canada

	Arsenic	Copper	Lead	Nickel	Zinc	Total suspended matter	Radium 226
A. Authorized levels of substances							
Maximum authorized monthly arithmetic mean concentration	0.5 mg/L	0.3 mg/L	0.2 mg/L	0.5 mg/L	0.5 mg/L	25.0 mg/L	10.0 pCi/L
Maximum authorized concentration in a composite sample	0.75 mg/L	0.45 mg/L	0.3 mg/L	0.75 mg/L	0.75 mg/L	37.5 mg/L	20.0 pCi/L
Maximum authorized concentration in a grab sample	1.0 mg/L	0.6 mg/L	0.4 mg/L	1.0 mg/L	1.0 mg/L	50.0 mg/L	30.0 pCi/L
B. Determination of frequency with which undiluted effluents are to be sampled and analysed for particular substances							
At least weekly if concentration is equal to or greater than	0.5 mg/L	0.3 mg/L	0.2 mg/L	0.5 mg/L	0.5 mg/L	25.0 mg/L	10.0 pCi/L
At least every 2 weeks if concentration is equal to or greater than	0.2 mg/L	0.1 mg/L	0.1 mg/L	0.2 mg/L	0.2 mg/L	20.0 mg/L	5.0 pCi/L
At least monthly if concentration is equal to or greater than	0.10 mg/L	0.05 mg/L	0.05 mg/L	0.10 mg/L	0.10 mg/L	15.0 mg/L	2.5 pCi/L

Source: "Metal Mining Liquid Effluent Regulations and Guidelines", Water Pollution Control Directorate, April 1977, Fisheries and Environment Canada.

Table 9.3C Authorized Levels of Effluent pH

Minimum authorized monthly arithmetic means pH: 6.0
Minimum authorized pH in a composite sample: 5.5
Minimum authorized pH in a grab sample: 5.0

Source: Same as above.

Table 9.3D Petroleum Refinery Effluent Regulations, Canada

Schedule I: Amounts to be used in calculating authorized deposits of deleterious substances

	Oil and grease	Phenols	Sulfide	Ammonia nitrogen	Total suspended matter
Monthly amount in pounds per 1,000 barrels of crude oil	3.0	0.3	0.1	3.6	7.2
One day amount in pounds per 1,000 barrels of crude oil	5.5	0.55	0.3	5.7	12.0
Maximum daily amount in pounds per 1,000 barrels of crude oil	7.5	0.75	0.5	7.2	15.0

Schedule II: Amounts to be used in calculating additional authorized deposits of deleterious substances when storm water is being discharged and limits of deposits authorized

	Oil and grease	Phenols	Total suspended matter
Pounds per 10,000 Canadian gallons of storm water	1.0	0.1	3.0
Pounds per month per 1,000 barrels of crude oil per day	25.0	2.5	75.0

Source: Environment Canada, Report EPS 1-WP-74-1.

Under the Canada Water Act, 1970, all waste discharges into a "designated water quality management area" must be approved by the federal government. No such areas have yet been established and no regulations have been made. The more significant federal water management statute is the Fisheries Act, 1952 (amended), which generally prohibits the deposition into waters of wastes, including waste heat, that degrade water quality and fish habitat. The act provides the federal Department of the Environment with the power to require modifications in a company's processes to protect fish-bearing waters.

Also, under the Fisheries Act, sections 33 and 34, the federal government issues regulations governing liquid effluents into water. Of relevance here are regulations setting allowable concentrations of total suspended matter and radium- -226 in uranium mine liquid effluents, and ammonia and total suspended matter from petroleum refineries (Table 9.3). Regulations related to the petrochemical and electric power generating industries are being developed. There are no liquid effluent regulations or guidelines proposed for coal-mining or gas extraction. The Atomic Energy Control Board (AECB) is the federal agency responsible for radiation control at nuclear mining, refining, and generation installations. It is consulted in the establishment of related federal environmental standards, and all relevant federal and provincial standards and objectives are written into the licence for a facility that is issued by the AECB.

The National Energy Board is responsible for issuing licences to import or export any petroleum, natural gas, or electricity and to construct pipelines and international electric power transmission lines. In applying for these licences, applicants must demonstrate that all relevant federal environmental standards and guidelines will be met. Also, the International Joint Commission, Water Quality Board, makes recommendations on water-quality objectives for the Great Lakes and the St. Lawrence River.

In summary, the federal government has the power to set water-quality emission standards to protect public health and to enforce international agreements. It also has the power to establish liquid effluent standards and has done so for certain industries. Under the British North America Act, resources and environmental management fall primarily under provincial jurisdiction. For this reason, federal involvement in Ontario has been limited largely to issues of international jurisdiction and co-operative arrangements whereby provincial authorities agree to enforce standards and objectives at least as stringent as the national objectives. The approach of the federal government is to establish national objectives and specific emission standards for industries of special concern. Enforcement of all standards and objectives in Ontario is left to provincial authorities, as set out in the "Canada-Ontario Accord for the Protection and Enhancement of the Environment".

Provincial. The main water management objectives set out by the Ontario Ministry of the Environment are as follows:[3]

1. To ensure that the surface waters of the province are of a quality that is satisfactory for aquatic life and recreation; where existing water quality does not meet these objectives, all practical measures shall be taken to upgrade the water quality. Effluent requirements will be established on a case-by-case basis taking into account the characteristics of the receiving waters. Substances with zero tolerance limits shall not be released, and releases of substances for which no objectives have yet been established shall be minimized.
2. To ensure a fair sharing of the available supply of water to protect both withdrawal and in-place uses of water. Surface water takings are controlled by a permit system to prevent interference with other uses wherever possible.
3. To protect the quality of ground water for the greatest number of beneficial uses. Emphasis is on drinking supply and agricultural uses. Where practicable, treatment or elimination of pollutants will be required to correct impairment. Where this is not practicable, replacement of contaminated water supplies may be required.

4. To ensure the fair sharing and conservation of ground water. Ground-water takings are controlled by a permit system to prevent interference with other uses wherever possible.

Specific water-quality objectives designed to achieve these broad objectives and related to energy projects are set out in Table 9.2. Authority to enforce these objectives stems from the Ontario Water Resources Act. These objectives are based on data from experiments where healthy stress-free organisms are exposed to one variable at a time, and consequently do not take into account synergistic effects. These effects could increase the toxicity of certain concentrations of contaminants, so one cannot be overly confident that toxic effects will not occur, even at the "objective level".

In all cases, the province, through the Canada-Ontario Accord for the Enhancement and Protection of the Environment, has undertaken to enforce effluent requirements, whether they are federal or provincial.

Radiation Standards

Because of the unique nature of radiation hazards and the public concern about these hazards, radiation standards for both air and water are discussed separately and presented in Table 9.4. These standards are developed primarily by the AECB, which relies heavily on several international and U.S. bodies, including the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the U.S. Biological Effects of Ionizing Radiation Committee (BEIR), and the United States Federal Radiation Council (FRC). Committees of specialist representatives from provincial and federal jurisdictions advise the AECB and provincial environment authorities on appropriate standards and objectives. On the basis of these standards, AECB determines derived release limits (DRL) that stipulate the quantity of each radioisotope that may be emitted by a nuclear facility. DRLs are stated for tritium, noble gases, iodine, and particulates in air, and for tritium and other radionuclides in water.

Table 9.4 Radiation Standards and Objectives

A. Maximum permissible doses (rems per year)[a] (Canada)

Organ or tissue	Atomic radiation workers	General public
Whole body, gonads, bone marrow	5[b]	0.5
Bone, skin, thyroid	30	3[c]
Hands, forearms, feet, ankles	75	7.5
Lungs and other single organs or tissues	15	1.5

B. Maximum permissible exposure to radon daughters (Canada)[d]

Unit and time period	Atomic radiation workers	General public[e]
WLM per 3 months	2	–
WLM per year	4	0.4

C. Drinking water standards and objectives (picocuries per litre)

Jurisdiction	Gross beta emitters	Sr 90	Ra 226[f]
Canada			
maximum permissible (standard			10 (27)
desirable objective	–	–	(2.7)
Ontario (objectives)	1,000	10	3
U.S.A.	1,000		

Notes:

a) Includes dose contributions from sources of ionizing radiation both inside and outside the body.

b) The dose to the abdomen for atomic radiation workers shall not exceed 0.2 rem per 2 weeks, and in the case of pregnant women, shall not exceed 1 rem during the pregnancy period.

c) The dose to the thyroid of a person under the age of 16 years shall not exceed 1.5 rem per year.

d) For exposure to radon daughters, the maximum permissible exposures (in WLM) apply instead of the maximum permissible doses for the lungs (in rem).

e) The WLM unit is only appropriate in occupational situations. In non-occupational situations, the maximum permissible annual average concentration of radon daughters attributable to the operation of a nuclear facility shall be 0.02 WLM.

f) Figures in brackets indicate levels being recommended by a Federal-Provincial Committee on Drinking Water Quality, as a result of its review of recent ICRP recommendations.

Sources: Atomic Energy Control Regulations, Schedule II. Ontario Ministry of the Environment, "Water Management", 1978. "Monitoring Program Design Recommdendations for Uranium Mining Localities", Environment Canada 1979.

A routine condition of AECB licences is a requirement that the company or utility comply with all federal and provincial environmental health and safety regulations.

Ontario provincial authorities have generally accepted AECB radiation standards and have not adopted standards or objectives of their own, with the exception of drinking-water quality objectives. Table 9.4 (part C) sets out the federal and provincial requirements, indicating a substantial difference for limits of radium-226 concentration in drinking water. Although the province uses a 1.2 micron filter and the federal government uses a 3.0 micron filter to measure dissolved radium levels, preliminary studies indicate that the different measurement techniques "do not have an appreciable or even consistent effect on the dissolved radium measured".[4] The problems that can arise from having different federal and provincial standards were illustrated in evidence before the Environmental Assessment Board during its hearing on the expansion of the uranium mines at Elliot Lake. Both the Town of Serpent River and parts of the Serpent River Indian Reserve draw their water from a stretch of the Serpent River that in recent years has experienced concentrations of 4-6 pCi/L of radium-226. These levels are above the provincial objective and treatment was therefore instituted to reduce radium concentrations in the town's water supply. Indian families on the reserve, which is within federal jurisdiction, did not benefit from such treatment, however, because the water supply met federal standards.

A Federal-Provincial Working Group on Drinking Water has recommended revised drinking water-quality criteria for radionuclides, based on recent ICRP recommendations. These recommendations (Table 9.5) set out maximum acceptable as well as objective or target concentrations for a greater number of radionuclides than are at present controlled. They also offer an opportunity to make federal and provincial objectives consistent, one with the other. It should be noted that none of the existing or recommended standards and objectives include uranium, thorium-230, thorium-232, or lead-210, all of which are heavy metals associated with the uranium fuel cycle.

Table 9.5 Criteria Recommended by the Federal-Provinical Working Group on Drinking Water (becquerels[a] per litre)

Radionuclides	Maximum acceptable concentration[b]	Objective (target) concentration[c]
Tritium	40,000	4,000
Strontium 90	10	1
Iodine 131	10	1
Caesium 137	50	5
Radium 226 (total)	1	0.1

Notes:
a) One becquerel (Bq) = 27.02 pCi.
b) Maximum acceptable concentration is intended to apply to transient situations. Radionuclide concentrations exceeding this level may be acceptable provided the duration of the increase is short and the annual average concentrations remain below this level and meet the ICRP restrictions for multiple radionuclide exposure, namely that: $\Sigma C_0/C_{ma} \leq 1$ where C_0 = observed radionuclide concentrations, C_{ma} = maximum acceptable radionuclide concentrations.
c) The objective, or target, concentration is intended as a guideline for life-long continuous consumption (at 2 L per day per person). Radionuclide concentrations exceeding this level are acceptable provided the situation is reviewed by health authorities, taking into account factors such as magnitude and duration of population exposure.
Source: Personal communication, Alun James, Ontario Ministry of Labour.

Monitoring and Enforcement

In order to assess the effectiveness of environmental quality standards, it is necessary to consider the regulating authorities' monitoring capability and enforcement mechanisms, without which standards and objectives remain paper tigers. There are two components to the environmental monitoring programme in Ontario. The first is a general monitoring programme to provide a reading of the quality of the ambient water and air environments of the province. The second consists of the various legal requirements placed upon industries and individuals to report contaminant emissions to provincial and federal authorities. Enforcement procedures and mechanisms follow directly from federal and provincial legislation and are discussed in the context of the relevant acts.

Monitoring

The major effort at monitoring air quality in Ontario is a federal-provincial programme that had 96 sampling stations throughout the province in 1977, monitoring for some or all of the following contaminants: sulphur dioxide, reduced sulphur, ozone, carbon monoxide, hydrocarbons, nitrogen dioxide, nitric oxide, other nitrogen oxides, and suspended particulates. In addition, Ontario Hydro had 47 sampling stations monitoring sulphur dioxide levels in the vicinity of its generating stations.[5] These data

are supplemented by special sampling programmes of the federal and provincial environment authorities, for specific purposes such as problem monitoring (e.g., fluoride on Cornwall Island, and lead in the vicinity of lead smelters) and the development of air-quality objectives.

An even more extensive sampling station network is in place to monitor water quality in Ontario. This network is operated by the province and grew from 210 stations in 1964 to 805 stations in 1976. Twenty-eight parameters and some of their compound forms are monitored, including: acidity and pH, suspended and dissolved solids, ammonia, nitrates, sulphates, cadmium, zinc, and mercury.

In addition to these regular monitoring programmes, which are intended to provide an indication of ambient environmental quality, emitters of contaminants are required to report such emissions to federal or provincial authorities. Sections 13 and 15 of the Environmental Protection Act require any person who emits a contaminant into the environment in excess of allowable concentrations prescribed in the regulations, or out of the normal course of events, to notify the Ministry accordingly. At the federal level, regulations under the Clean Air Act and the Fisheries Act specify reporting requirements for contaminant emissions, as set out below.

The Clean Air Act

Fuels Information Regulations, No. 1:

- Applies to all liquid fuels originating from crude oils, coal, or bituminous sands
  - Every person producing in Canada or importing more than 400 m^3 of fuel must submit:
    1. a report on sulphur content on or before January 31 following the end of the calendar year during which the fuel was produced or imported
    2. a liquid additive report (where applicable) stating composition of fuel additive and indicating any known adverse effects on human health. Any changes in the additives must be reported within 60 days.

The Fisheries Act

Metal Mining Liquid Effluent Regulations and Guidelines:

- Sampling and analysis requirements are as set out in Table 9.3.
- New expanded or re-opened mines must sample and analyse undiluted effluents once a week for the first six-months of operation.
- Where mean contaminant emission concentrations for a six-month period are less than those set out in column 3 of Table 9.3B, a mine operator must sample undiluted effluent every six months.
- Within 30 days after the end of each month a report must be submitted to the Minister of Fisheries and Environment containing:
  1. arithmetic mean contaminant concentrations and pH of all undiluted effluents
  2. actual contaminant concentrations and pH values from which the arithmetic means have been calculated
  3. volumes of undiluted effluents deposited
  4. type of sample collection used

Petroleum Refinery Effluent Regulations and Guidelines:

- Calculation and monitoring of actual and authorized effluent deposits of deleterious substances is prescribed, deleterious substances being those set out in Schedule 1 of Table 9.3D.
- Reporting of information on effluents is prescribed and includes:
  1. daily authorized and actual deposits and monthly arithmetic mean of the authorized and actual deposits of deleterious substances
  2. pH of composite sample
  3. other information as may be required by the Minister of Fisheries and the Environment

Atmospheric conditions in Ontario mines are regularly monitored by the Ministry of Labour, Mining Health and Safety Branch. The emphasis in this monitoring programme is to ensure that workers are not exposed to radon gas above the levels stipulated in the Atomic Energy Control Regulations.

Enforcement

Enforcement of federal environmental standards for contaminants mentioned in the Clean Air Act and the Fisheries Act is left primarily to provincial agencies. In the case of Ontario, this arrangement is set out in the Canada-Ontario Accord for the Enhancement and Protection of the Environment, previously mentioned, whereby the province agrees to establish and enforce environmental standards at least as stringent as those set out by federal guidelines. Federal air-quality objectives and water-quality guidelines are not legally enforceable, that is, they are not standards. Federal authorities rely on provincial monitoring and enforcement. Where federal agencies or Crown corporations are involved, the federal government co-operates with the province in remedying any environmental problems encountered.

At the federal level, enforcement of environmental quality standards is limited primarily to regulatory activities of the Atomic Energy Control Board. When an operator of a uranium mine, mill, refinery, or depository, or of a nuclear facility, receives a licence from AECB, which he must do, the licensee is subject to compliance inspections by AECB officers. Discussion of how the licensing and inspection procedure applies to nuclear generating stations was presented in the RCEPP *Interim Report on Nuclear Power in Ontario*.[6] It was concluded at that time that:

- Regular inspection reports should be made public.
- More frequent licence reviews should be considered.
- AECB should have the power to order corrective actions as an enforcement mechanism less severe than licence suspension.

In the case of uranium mines, the AECB's interests have historically been directed to the security of uranium and to information regarding reserves, production, and disposition. Safety and health aspects have been left to provincial authorities, and the position of the federal government has until now been that, except for matters concerning national security and foreign policy, uranium mines should be regulated at the provincial level in much the same manner as all other mines. More recently, the AECB has appointed a full-time officer to monitor mining and milling operations at Elliot Lake. Under the previous federal government, it had been proposed in Bill C-14 that the AECB take an expanded role in the regulation of the front end of the uranium fuel cycle. This bill died on the Order Papers, and any changes must now await the introduction of another bill by the new government. It would appear, however, that some changes are likely to take place in the traditional roles of the federal and provincial governments in this area. Meanwhile, under the current arrangements, the AECB appoints provincial officials from the Ministry of Labour, Mining Health and Safety Branch, as inspectors under the health and safety sections of the Atomic Energy Control Regulations. Radiological protection provisions were incorporated into these regulations in 1960 (Tables 9.4A and B). An objective of 0.3 working level (WL) concentration of radon daughters was recommended by the ICRP in 1959 and adopted in 1960 by the AECB and the Ontario Department of Mines and Health as a target to be attained within five years. Provincial regulations (in the form of an order under the Mining Act) were not issued until 1967, however, and the required control levels were not reduced to 0.3 WL until 1975, 15 years after the original recommendation was made.

In 1974, the AECB established a federal-provincial Mine Safety Advisory Committee, and revised its regulations to require applicants for licences to submit to this committee information on procedures to be followed and health and safety measures to be incorporated in normal operations. During operations, licensees must submit periodic reports on contaminant concentrations and employee exposures, total contaminant emissions, unusual events, and changes in procedure. Nevertheless, the policy is, clearly, that provincial agencies have operational responsibility for health and safety in uranium mines.

The Province of Ontario has at its disposal a number of enforcement mechanisms to ensure compliance with environmental quality and occupational health and safety objectives and standards. These are administered by the Ministry of the Environment and the Ministry of Labour.

The Chief Mines Engineer, Mining Health and Safety Branch, Ministry of Labour, has the authority under Part IX of the Mining Act to issue codes concerning operating practices and the quality of the work environment in mines, and requiring certain procedures and conditions to be met. These codes, however, do not have the force of law. The Royal Commission on the Health and Safety of Workers in Mines recommended, in 1976, that legislation with greater clarity and flexibility replace Part IX of the Mining Act and that joint worker-management committees be established in mines and plants to

determine practices related to occupational health and safety, and to investigate accidents and complaints of unsafe working conditions. It also recommended that workers have the right to refuse dangerous work and that more research into and monitoring of occupational disease be conducted. These concerns are all addressed in Bill 70, "An Act Respecting the Occupational Health and Occupational Safety of Workers", which received third reading in December 1978 and was expected to be proclaimed in the fall of 1979.[7] The Bill provides for the setting and enforcement of regulations governing atmospheric conditions and the monitoring thereof in a work-place, the reporting of occupation-induced sickness or injury, and the handling of toxic substances. This is the first time that comprehensive control over work-place environmental conditions has been made possible at the provincial level. It must be noted, however, that such control is not yet in effect, and will not be until Bill 70 is proclaimed and regulations are made. Control will only be as comprehensive as provided for in the attendant regulations.

The Ministry of the Environment has available three mechanisms of enforcement under the Environmental Protection Act (EPA). Pursuant to Sections 10 and 11 of the EPA, a company emitting or likely to emit contaminants may apply for a "programme approval" which sets out an approved programme of emission controls. While a company is not required to receive a programme approval, there is an incentive to do so, since any company or individual that is in compliance with a programme approval cannot be convicted of an offence under the EPA. Offences under the Act are punishable by fines of up to \$5,000 for the first offence and \$10,000 per day for each successive offence. Nevertheless, programme approvals would be a much more effective enforcement mechanism if they were mandatory for plants emitting designated contaminants into the environment. This does not apply to nuclear generating and refining plants, which already receive a programme approval in the AECB licensing process, but could certainly apply to uranium mining and milling operations for which AECB licence enforcement provisions are less suitable, and also to fossil generation plants.

The Ministry of the Environment can issue a "control order" where a violation of the regulations or of section 14 of the EPA has been detected. Such an order can require the polluter to limit, control, or stop the emission of contaminants into the natural environment. A control order cannot be issued until 15 days after written notice of the intention to issue a control order, with reasons for so doing, is received by the person to whom the order applies. Alternatively, where there is an immediate danger to human life, health, or property, a "stop order" can be issued without prior notice, and such an order takes effect immediately. A stop order requires the person to whom it is issued to cease emitting into the environment the contaminant(s) of concern, either permanently or for a specified period of time. Notably, grounds for issuing a stop order do not include an apparent immediate danger to plant, animal, or fish life.

In addition, there are a number of approvals for which mine operators must apply to the provincial government. These include:

Approval from the Ministry of Natural Resources

- under the Public Lands Act
  - to access to property over Crown land
  - for land tenure of tailings deposit areas
- under the Forest Fire Prevention Act
  - for a work permit for road construction, land clearing, and dam, bridge, or camp construction
- under the Lakes and Rivers Improvement Act
  - of tailings containment design and construction
- under the Mining Act
  - to open a pit and develop a mine

Approval from the Ministry of the Environment

- under the Ontario Water Resources Act
  - to take water in excess of 10,000 gallons per day
  - to treat and distribute potable water
  - to establish sewage works, including industrial waste treatment works
- under the Environmental Protection Act
  - for mine upcasts and mill emission points
  - for disposal of domestic waste

Discussion

In recent years, the matter of environmental and occupational health and safety standards has been reviewed in various contexts by a number of high-level bodies, including the Royal Commission on the Health and Safety of Workers in Mines (Ham, 1976), the Science Council of Canada (1977), the Cluff Lake Board of Inquiry (Bayda, 1978) and the Environmental Assessment Board (1979). The next section gives a synthesis of the findings of these reports that are relevant to the purpose of this volume.

The major relevant issues are:

- The adequacy of standards and objectives, and of the monitoring and enforcement mechanisms and activities.
- The overlap of jurisdictions between federal and provincial levels and among ministries of the province.
- The relationship of occupational health standards to general environmental standards.
- The openness and accessibility of the standard-setting process.

The Adequacy of Regulations and Regulatory Procedures

Environmental Standards. In a study of six hazardous materials and their control, including oxides of nitrogen and radioactive substances, the Science Council of Canada (1977) concluded that oxides of nitrogen represent a subtle environmental problem, and that not enough is known about their synergistic effects with other materials.

Testimony at the Elliot Lake hearings on the expansion of uranium mining facilities before the Environmental Assessment Board revealed some uncertainty about the effects of nitrate levels in water. Ontario's water-quality objectives stipulate a level for nitrate only with reference to drinking water. In the presence of phosphates, however, nitrates can lead to water-body eutrophication. Mr. Justice E. Bayda (1978) and the EAB (1979) both pointed to the lack of standards or objectives for thorium-230, thorium-232, lead-210, and undissolved radium-226. Although the likelihood of dangerous concentrations of these contaminants accumulating in water is low, it is considered important to monitor these elements regularly as indicators of water quality and to ensure that levels are not of concern. In general, non-human life forms are less sensitive to radiation than humans, and standards or criteria that protect humans adequately are more than safe for other animals and for plants. Nevertheless, it is noted that the objective for radium-226 is based on a drinking-water criterion, and a total radium-226 level would be more appropriate for the protection of aquatic life. There is also no standard or objective stated for vanadium, a heavy metal associated with the uranium mining and milling process, except in the Ontario objectives for irrigation waters (0.10 milligrams per litre).

Perhaps the most serious shortcoming of regulations governing the uranium fuel cycle is the lack of any specific guidelines or requirements governing post-closure management of sites and waste areas at mines and nuclear plants. The major radioactive constituent of uranium tailings is thorium-230, which has a half-life of 80,000 years. Tailings piles therefore remain hazardous for several hundred thousand years. The major hazard from tailings piles is posed by the escape of radon gas from the decay of thorium-230 to radium-226 and its daughters. This hazard is insignificant at distances beyond 2 km from tailings piles, due to the rapid dispersal of radon gas. But the tailings remain dangerous, and abandoned tailings areas should be fenced and appropriate signs posted, as minimum measures of public protection from this long-term hazard. Tailings should also be covered to prevent the dispersal of radioactive dust. The most difficult long-term aspect of tailings management is the monitoring and surveillance of surface and ground waters to ensure that radium and acid leachate do not cause widespread water contamination.

Similarly, the decommissioning of nuclear plants and the management of spent fuel involve the long-term disposal of radioactive wastes. These wastes do not remain radioactive as long as tailings, since the major radioactive decay takes place within 500 years. However, the danger from these wastes may long outlive the organizations initially responsible for their production.

Both the Ontario government and the federal government have given these concerns some attention, but they have not yet been able to develop appropriate regulatory procedures. Ontario has given the most attention to the matter of tailings management, but it is not yet clear which ministry will receive this regulatory responsibility.

At the federal level, the present policy is to store all radioactive wastes in temporary facilities, until permanent disposal mechanisms have been developed and approved. Current storage facilities will be

adequate until the early 1990s, when more permanent disposal solutions will be required. In order to meet this time frame, the Atomic Energy Control Board is working on regulations governing nuclear waste disposal and expects to have them ready for public review and approval by 1981. An important contribution to the preparation of these draft regulations will undoubtedly come from the Joint Senate and House Committee inquiring into nuclear energy. Included in the terms of reference of this committee is a mandate to inquire into the following:[8]

- the risks of nuclear generation in comparison with the risks of the practical alternatives
- the basis for and adequacy of national nuclear, health, safety, and environmental standards, and of compliance monitoring
- federal instruments, structures, and responsibilities for the development and regulation of nuclear equipment, technology, materials, and facilities
- the role of federal agencies and the adequacy of federal legislation in the event of a nuclear accident, and for the prevention of harm to man and the natural environment

In considering the management of tailings, Bayda concluded that responsibility for long-term monitoring and surveillance should not rest with mining companies, which may go out of existence, and that regulatory agencies should undertake this task. He also concluded that a fund should be established to cover the costs of long-term monitoring and surveillance and non-recoverable costs of decontamination. Such a fund should be established with the participation of all parties that benefit from the mining of uranium.[9]

It is particularly important to recognize that the post-closure regulation of uranium mines and nuclear facilities is a necessity whether or not the nuclear energy option is chosen in the future. Uranium mines and nuclear facilities that are now in operation must be regulated for effective, safe decommissioning and closure. To link the discussion of these regulations with the wider debate surrounding nuclear energy could result in costly delays, and would serve no useful purpose.

Occupational Health Standards. The Ham Commission, in reviewing standards to protect the health of uranium miners, found that there was insufficient knowledge of the dangers of thoron gas to miners. It recommended that "the Atomic Energy Control Board confirm the extent to which thoron gas and its daughter products contribute to the irradiation of the respiratory system and other organs of workers in Ontario uranium mines".[10] Ham also recommended that the Atomic Energy Control Regulations "delineate how the components of external and internal irradiation are to be accounted for and how total exposure and related dose is to be evaluated".[11] This shortcoming would appear to have been overcome by the publication of the amended Schedule II of the AEC Regulations in January 1978. Mr. Justice Bayda noted, however, that Schedule II could be interpreted as allowing a total dose greater than 5 rem per year for workers, since the exposure to radon, which is expressed in working-level-months, could be considered as being in addition to the 5 rem limit. This requires clarification.

Also, with respect to occupational health and safety standards, Ham, Bayda, and the Province of Ontario (in submissions to the EAB at Elliot Lake), all noted that provisions of the Canada Labour Code are not comprehensive, particularly where health protection is concerned. It is concluded that the Province must ensure that adequate occupational health standards are in place, at least until such time as federal standards are upgraded. For this reason, it is considered essential that the new Occupational Health and Safety Act come into effect in the near future.

Both Ham and Bayda rejected the sometime practice of job or location rotation of atomic workers to limit radiation exposures.

Public Health Standards. Bayda was critical of the radiation dose limit of 500 millirem per year for the general public, which is high when compared with the annual average of 170 millirem derived from the ICRP recommendation of a 5 rem per 30-year dose limit. It is also far higher than the German standard (30 millirem) and the U.S. Environmental Protection Agency's recommended annual dose limit (25 millirem) for the general public. Furthermore, the 500 millirem level is many hundred times higher than exposures that have been experienced during normal operating practice of nuclear facilities in Canada and the U.S. Bayda recommended that Canadian authorities should "consider the adoption of legal limits for the exposure of the general public which are closer to actual operating practice".[12] The Environmental Assessment Board found that "all experts agreed that if adherence to the existing radiation standards and guidelines is coupled with the ALARA (as low as reasonably achievable) principle, the expansion (of the Elliot Lake uranium mines) could be carried out without exposing the people of the Elliot Lake area to unnecessary or unacceptable radiological health hazards".[13] The need to couple the radiation standard with the ALARA principle reflects a concern that radiation levels

should not and need not reach the maximum allowable levels, and lends some support to the Bayda recommendation.

The ALARA principle merits further discussion. In the context of the current state of knowledge and technology, that is, when it is unclear at what point exposure to radiation is sufficiently minimal to produce no discernible health effect, "as low as reasonably achievable" may one day turn out to be not low enough from the standpoint of health protection. The debate on this point hinges partly on the definition of what is "reasonable". It is somewhat easier to accept application of the ALARA principle to emissions from nuclear generating facilities, which, experience has shown, can operate under normal conditions emitting only small amounts of radioactivity, than it is to accept its application to radon levels in uranium mines that have experienced great difficulty reducing exposure levels. Even in the former case, however, there is some question about the long-term effects of tritium releases now being experienced at nuclear generating stations. In this context, adoption of the ALARA principle seems prudent only if certain qualifications are attached. The first qualification is that the definition of what is considered "reasonably achievable" be determined by a regulatory body with the participation of all affected parties, including workers and the public. The definition of "reasonable" should not be a point of negotiation on any bargaining table where other pressures can be brought to bear that may distract attention from the overriding concern – health. The second qualification is that it must be understood that the ALARA principle is not a substitute for a standard or objective, and that every effort must continue to be made to establish the necessary criteria upon which less contentious standards can be based. And, finally, great care must always be taken to ensure that all options to minimize risk are considered. For example, the EAB recommendation that a 2 km buffer zone be established around all tailings areas should be implemented.

Monitoring and Enforcement. The monitoring of occupational environments has also come under scrutiny. Ham found: "It is of the highest importance that a reliable personal dosimeter for alpha radiation be developed for use in the mines and that a reliable 'instant' working level meter be developed to facilitate engineering monitoring of mine environments."[14] Also, with respect to monitoring technology, the EAB concluded that instrumentation for measuring long-term radon exposure levels at tailing sites must be developed.[15] In its recommendations on the expansion of the Elliot Lake uranium mines, the EAB also urged that "periodic intensive scans (for heavy metals in water) should be carried out by the Province at the existing monitoring points".[16]

On the question of responsibility for carrying out monitoring programmes, the EAB reported: "Whereas the Board was told that dams are monitored every two months, the Board found it difficult to determine what other areas are inspected regularly and by whom."[17] In a similar vein, Bayda was critical of the federal Metal Mining Liquid Effluent Regulations, because they "cast no specific duty on the federal officers to conduct a surveillance of . . . records submitted by mine operators . . . and of actual monitoring and sampling undertaken".[18] These concerns lead to the question of the evaluation of enforcement mechanisms to ensure compliance with standards and objectives.

In its review of radiation hazards, the Science Council of Canada concluded that, although regulation of radiation exposure from the nuclear fuel cycle has been predominantly a federal responsibility, "there is no evidence to indicate that this has 'of itself' assured the best attainable control of this radiation hazard".[19] The problems lay in the frequently permissive and non-obligatory nature of the controls. "We have been impressed by the testimony of individuals most affected by the major occupational hazards we have studied, to the effect that there is no reason why they should have any confidence in a system of 'guidelines' or 'non-enforceable standards'.[20] The Science Council committee went on to recommend that enforceable and more specific statutory provisions to regulate major environmental hazards be promulgated in order to sustain public confidence in the process of hazard measurement and control.

With respect to the nuclear regulatory system, Bayda concluded that stronger federal-provincial communication and co-operation were needed, and that monitoring and compliance inspectorates must be strengthened. It was his view that regulatory agencies, particularly the AECB, rely too heavily on the plans of industry in determining licensing requirements, and he advocated more active, independent prescription of construction and operating requirements by the regulators. More detailed regulations and an expanded regulatory staff are required to fulfil these recommendations, and it is most disturbing that, according to recent statements by the president of AECB, indications point to a reduction of AECB budget and staff and certainly no increases.[21] It cannot be emphasized strongly enough that the

costs of regulation must be considered an integral part of the nuclear programme, and that an expansion of the programme must be paralleled by an expansion of the regulatory bodies. This is especially the case where there are great uncertainties about the risks involved. Only the most vigilant and visible regulation of the nuclear industry will help to increase the acceptability of nuclear risks.

Jurisdictions

It has been a consistent finding of reviews of environmental and occupational health controls that the enforcement of standards and objectives has been seriously hampered by jurisdictional confusion and conflict. The Environmental Assessment Board comments: ... the confusion between jurisdictions has led in the past to difficulty in identifying with precision the department or body actually responsible for any existent situation ... jurisdictional responsibility should be clearly defined so that the public can appreciate "who is responsible for what".[22]

Bayda recommended the formation of a federal-provincial committee to resolve jurisdictional disputes and uncertainties surrounding the regulation of the nuclear industry in Saskatchewan: "The present Inquiry has demonstrated that there has been considerable confusion and uncertainty between the two levels of government, especially at the compliance end of the regulatory process."[23] The Ontario Secretariat for Resources Development also commented: "The definition of the situation in and associated with a uranium mine-mill is much less clear and is dependent to a substantial degree on the working arrangements that have evolved (and are evolving) between Ontario and federal agencies."[24]

The situation has been further complicated by the federal Minister of Labour's announcement in December 1978 that the federal government intends to effect a realignment in the responsibilities for occupational health protection under the amended Canada Labour Code. Previously, provincial officers were considered responsible for ensuring compliance with occupational health requirements.

To clarify the jurisdictional issues, the Science Council's Committee on Policies and Poisons recommended that provinces set statutory levels of exposure and contaminant concentrations for both the occupational and general environments, and that it be the role of the federal government to regulate its own activities and industries that are clearly under federal jurisdiction, such as railroads, and to recommend maximum exposure levels. Thus, the federal role in occupational health regulation would parallel its role in environmental protection *vis-à-vis* the provinces. Both the Bayda and the Ham reports are consistent with this position, in that they recommend consolidated or strengthened provincial involvement in occupational health standard-setting, monitoring, and enforcement. There is no reason to disagree with this position.

Finally, with respect to jurisdictional concerns, it is essential that federal and provincial authorities work together to develop post-closure regulatory mechanisms. Consistent with the position that the province strengthen its involvement in the environmental and health regulation of mines would be the option of allocating responsibility for the long-term regulation, monitoring, and surveillance of uranium tailings deposits to the Ontario Ministry of the Environment. This would leave the post-closure regulation of nuclear facilities to federal authorities who have greater expertise in the back end of the uranium fuel cycle.

Standards for the Work-Place

A number of the observations made in the discussion of the adequacy of standards, enforcement, and related jurisdictional concerns have focused on occupational health specifically. Controversy over the long-term effects of low-level exposure to contaminants, and compliance difficulties, has been most severe. This is understandable, because the handling of hazardous materials is more often necessary in the work-place than in the general environment. One consequence of this is that the appropriateness of health standards and the degree of compliance with these standards are more critical concerns for occupational environments than for the general environment. It follows that particular attention should be given to these concerns, and it has been. Indeed, the Royal Commission on the Health and Safety of Workers in Mines reviewed the regulation of occupational environments extensively.

One matter the debate on occupational health standards has centred on is whether or not standards for workers should differ from standards for the general public. Bayda adopted the ICRP philosophy on occupational hazards of radiation, namely, that regulation should be such that the risk to atomic workers from radiation is no more than the levels of risk endured by workers in other industries considered to have high standards of safety. Taking an average dose of 0.5 rem/year received by an atomic

worker, it was calculated that an additional 50 deaths per million workers per year would result from this exposure. This compares favourably with other occupational risks, and, on this basis, Bayda concluded that the occupational exposure standard is appropriate.

The Science Council's Committee on Policies and Poisons has also acknowledged that higher risks may be acceptable in the work-place than are acceptable in the general environment. "Ideally, people at work should not be subjected to greater risk than those outside the work-place. An acceptable risk may, however, be perceived differently for, on the one hand, a population with good health surveillance (workers) and, on the other hand, a general population that includes children, pregnant women, the aged and diseased."[25] The key to the acceptability of higher risk levels in the work-place, however, is careful monitoring of biological health and environmental conditions, and continuing research on the effects of occupational hazards, particularly low-level, long-term exposure of workers to toxic contaminants. The need for greater efforts in research of this kind was recognized by the Science Council, by the Royal Commission on the Health and Safety of Workers in Mines, and by the Cluff Lake Board of Inquiry. Critical to the achievement of the necessary co-operative sense of responsibility and awareness, comprehensive record-keeping, and resulting improved insights is a condition of openness in the setting and enforcement of standards.

Openness of the Regulatory Process

> There has been a serious lack of openness on matters of health and safety of workers in mines.... Workers have a right in natural justice to know about the risks and consequences of the risks that they undertake at work.[26]

> The acceptable levels of risk at work and in life-styles are being redefined by society. It is important that this process be marked by a higher measure of openness than has hitherto characterized government and industrial policy.[27]

> It is an essential condition of the process of deciding upon the acceptability of risk that there be openness in the decision-making process, so that individuals can participate in decisions on their own exposure levels.[28]

The most notable step in the direction pointed to by these venerable exhortations is the passage of Bill 70, the Occupational Health and Safety Act, 1978, in the Ontario Legislature. This statute provides for the establishment of worker-management health and safety committees, worker participation in surveillance and the establishment of safe procedures, the right of workers to refuse unsafe work, and the open review and discussion of proposed standards regulating toxic substances, among other things. These are gigantic steps in the resolution of many of the problems raised above, provided the regulations accompanying the legislation follow in the same spirit.

The importance of the widest participation in the setting, interpretation, and enforcement of standards and objectives also derives from the element of subjectivity of the criteria upon which standards and objectives are based. As noted at the beginning of this chapter, standards reflect not only scientific fact but also social and political values.

The principles enunciated by the Science Council's Committee on Policies and Poisons, as a guide to its work, form an apt summary of this discussion:

- All exposure of living things to harmful pollutants should be as low as practicable.
- The hazards associated with exposure to any substance or process should be assessed prior to the exposure.
- The hazards of exposure must be related to certain levels of probability of exposure, that is, the risk of exposure must be assessed.
- The regulatory process should inform exposed populations of these risks, and everyone should have the right to accept or reject these risks and to participate in selecting acceptable levels of exposure.
- All hazards, including suspected hazards, must be regulated by standards that are subject to change as new information becomes available.
- A standard should reflect an acceptable risk, and all standards must be measurable, achievable, and as uniform as possible across political jurisdictions.
- Ideally, people should not be subjected to greater risks in the work-place than outside. The acceptability of certain risks may be different, however, for a worker population with good health surveillance than for a general population which includes children, pregnant women, the aged and the diseased.

Estimates of the Health Effects of Electric Energy Production

Tables A.2 to A.9 list figures for the occupational and public deaths, disabilities, and equivalent man-days lost from the sources shown in Table A.1. The sources are not independent of each other. There is a good deal of cross-referencing between sources, and some use data from the same original sources (such as the Rasmussen Report: WASH-1400 for reactor accident risk assessment). The "selected range" for each category in the tables, where shown, is the range that appears in Table 6.1 of the main text, which summarizes the health effects of all the energy sources. The fact that it is so selected does not mean that we can give any more credibility to it than stems from the fact that it represents the range of values taken from a number of reputable sources with the substantial reservations that are discussed in the main text.

Comments on Sources (see Table A.1)

1. Ramsay's figures (I) generally relate to what he terms 1 USW of electrical energy, which he defines as 2×10^{19} kW·h – approximately the amount of electric energy that was generated in the United States in 1975. His figures have been reduced proportionately by the factor $0.75 \times 1{,}000$ MW·y/(2×10^{12} kW·h) = 304 to conform to the adopted standard of a 1,000 MW power plant operating for one year with a 75 per cent capacity factor.

2. Comar and Sagan (II) are among the most widely quoted sources for the health effects of fossil fuels and nuclear power. Their values are taken directly from Tables 3 and 4 of the publication cited. Comar and Sagan list the figures for accident and disease separately in most cases, but these have been added together under each heading in our tables. Comar and Sagan do not specify the capacity factor assumed for the "1,000 MW plant" to which their figures relate. Any adjustment between their capacity factor and our standard of 75 per cent would be insignificant compared with the range of values under most headings.

3. Inhaber (III) is one of the few workers who have attempted to include the (partial) risks of construction. His work has been strongly criticized in the report by Holdren et al. (VII). Generally, construction figures appear under the heading "other" in the tables. It should also be noted that Inhaber separates "processing", whereas other writers include processing with extraction. Therefore, while the figures under the three individual headings of extraction, processing, and transportation are different for different workers, the totals of the three are quite similar. Inhaber's figures relate to one megawatt year and have been multiplied by 750 for Tables A.2 to A.9.

4. The English summary of the Swedish report (IV) is largely qualitative, but certain figures have been extracted from the text and converted to the adopted standard.

5. The AMA report (V) is largely a repetition of Comar and Sagan (II), with some modifications.

6. WASH-1400 (VI) is now somewhat outdated, but it was a pioneering attempt to carry out the comparison of energy sources. It is still widely quoted.

7. The report of Holdren et al. (VII) contains a detailed critique of the Inhaber report (III). It is negative in tone and contributes little new information. Its effect appears to be to increase the upper limit to the health effects of nuclear power, at the same time reducing those for coal; and it appears to reduce the impact of hydro and alternative technologies relative to nuclear and coal. Holdren's "partial corrections" to the Inhaber figures differ from Inhaber's mainly in the above-mentioned areas. They are expressed only in man-days lost due to fatalities and disabilities from all causes. As in the Inhaber report, they relate to one megawatt year of power and have been multiplied by 750 for the purpose of the present report (1,000 MW, 75 per cent capacity factor).

8. The so-called Lewis report (VIII) is an excellent critique of Rasmussen's methodology. However, like Holdren's paper it contributes more to the uncertainty of the estimates of health effects than to their precision. It is largely qualitative, and only very few data have been extracted from it and adjusted to the standards of Tables A.2 to A.9.

9. The caution is repeated here that the health impact figures of Tables A.2 to A.9 should not be used alone to rank the sources of electric energy, but only as one of several inputs. Any serious attempt to

quantify the comparative health effects must go back to the methodology of the original work by which the figures were derived. Because figures are approximate and incomplete, they have been rounded off in most cases to two significant figures, which is generally more than they deserve Moreover, linear extrapolation has been used throughout as the only practical way of adjusting figures to a single standard for purposes of comparison. The lack of rigour in this process is recognized.

Table A.1 List of Sources for Tables A.2 to A.9

Reference	Author(s)	Title
I	William Ramsay	"Unpaid Costs of Electrical Energy." Baltimore, Maryland: Johns Hopkins University Press, 1979.
II	C.L. Comar and L.A. Sagan	"Health Effects of Energy Production and Conversion" in "Annual Review of Energy", 1976. Palo Alto, California: Annual Reviews Inc., 1976.
III	Herbert Inhaber	"The Risks of Energy Production." Fourth edition. Ottawa: Atomic Energy Control Board, June 1979.
IV	Sweden: Ministry of Agriculture and Environment	"Energy, Health and Environment." Report by the Swedish Governmental Committee on Energy, Health and the Environment. Stockholm, 1978.
V	American Medical Association, Council of Scientific Affairs	"Health Evaluation of Energy-Generating Sources." Report adopted by the American Medical Association, June 1978.
VI	United States Atomic Energy Commission	"Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy." Report WASH-1224. Washington, D.C., 1974.
VII	J.P. Holdren, et al.	"Risk of Renewable Energy Resources: A Critique of the Inhaber Report." Berkeley, California: University of California, June 1979.
VIII	H.W. Lewis et al.	"Risk Assessment Review." Report to the U.S. Nuclear Regulatory Commission. Washington, D.C., September 1978.

Table A.2 Estimates of the Annual Health Impact of the Fuel Cycle for a 1,000 MW Coal-Fired Power Plant (75 per cent CF)

Impact	Ref. [a]	Extraction	Processing	Transportation	Generation	Other	Total
Occupational deaths due to accident and disease							
	I	0.5–5.5	–	1–2	–	–	1.5–7.5
	II	0.45–4.5	0.02–0.04	0.06–0.4	0.01–0.03	–	0.54–5.0
	III	0.5–3.75	–	1.2–3.75	0.001–0.007	–	1.7–7.5
	IV	2–2.5	–	–	–	–	–
	V	0.45–6.0	0.02–0.05	0.06–1.9	0.01–0.03	–	0.54–8.0
	VI	0.98	–	0.055	0.03	–	1.1
Selected range	–	0.05–5.0	0.02–0.05	1–2	0.01–0.03	–	1.5–7
Occupational disabilities due to accident and disease							
	I	–	–	–	–	–	–
	II	23–97	2.6–3.0	0.33–23	0.9–1.5	–	27–125
	III	30–53	–	9.75–36	1.2–6.4	–	42–62
	IV	360	–	–	–	–	–
	V	23–128	2.6–3.1	0.33–23	0.9–1.5	–	26–156
	VI	40.5	–	5.1	1.2	–	46.8
Selected range	–	–	–	–	–	–	26–160
Occupational equivalent man-days lost from all causes							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	6,000–29,000	–	7,500–26,250	173–975	–	13,700–55,000
	IV	–	–	–	–	–	–
	V	–	–	–	–	–	–
	VI	8,330	–	570	350	–	9,250
	VII	–	–	–	–	–	14,250–32,250
Selected range	–	–	–	–	–	–	14,000–56,000
Public deaths due to accident and disease							
	I	–	–	1–2	1–32	–	2–34
	II	–	1–10	0.55–1.3	0.07–100	–	1.6–111
	III	1–10	–	0.6–1.4	0.15–27	–	1.8–39
	IV	–	–	–	–	–	–
	V	–	1–10	0.55–1.3	0.07–303	–	1.6–315
	VI	–	–	0.55	–	–	–
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	1.6–100
Public disabilities due to accidents and disease							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	–	–	1.2	750–162,000	–	750–162,000
	IV	–	–	–	–	–	–
	V	–	–	–	–	–	–
	VI	–	–	1.17	–	–	–
	VII	–	–	–	–	–	750–187,500
Selected range	–	–	–	–	–	–	750–190,000
Public equivalent man-days lost from all causes							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	6,300–63,000	–	3,750–8,700	4,500–1M	–	14,500–1.08M
	IV	–	–	–	–	–	–
	V	–	–	–	–	–	–
	VI	–	–	3,500	–	–	3,500
	VII	–	–	–	–	–	5,250–1.13M
Selected range	–	–	–	–	–	–	5,000–1M

Note a) See Table A.1 for details.
In cases where original data referred to a different power level the data have been adjusted in the ratio of that power to 750 MW.
Source: RCEPP.

Table A.3 Estimates of the Annual Health Impact of the Fuel Cycle for a 1,000 MW Oil-Fired Power Plant (75 per cent CF)

Impact	Ref. [a]	Extraction	Processing	Transportation	Generation	Other	Total
Occupational deaths due to accident and disease							
	II	0.06–0.21	0.04–1.0	0.03–0.10	0.01–0.04	–	0.14–1.3
	III	0.11–1.3	–	0.03–1.05	0.01–0.04	–	0.14–1.4
	IV	0.95	–	–	–	–	–
	VI	0.063	0.042	0.03	0.037	–	0.172
Selected range	–	–	–	–	–	–	0.14–1.4
Occupational disabilities due to accident and disease							
	II	7.5–21	3–62	1.1–9	0.6–1.5	–	12–94
	III	11.25–90	–	1.2–10	0.7–1.5	–	13–101
	IV	79	–	–	–	–	–
	VI	7.5	8.0	1.1	1.5	–	13.1
Selected range	–	–	–	–	–	–	12–100
Occupational equivalent man-days lost from all causes							
	II	–	–	–	–	–	–
	III	1.200–12,000	–	240–1,124	98–300	700	2,250–14,250
	IV	–	–	–	–	–	–
	VI	–	–	–	–	–	–
	VII	–	–	–	–	–	2,250–14,250
Selected range	–	–	–	-	–	–	2,250–14,250
Public deaths due to accident and disease							
	II	–	–	–	1–100	–	1–100
	III	–	–	–	0.03–28	–	0.03–28
	IV	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	1–100
Public disabilities due to accident and disease							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	–	–	–	150–162,000	–	150–162,000
	IV	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	150–160,000
Public equivalent man-days lost from all causes							
	II	–	–	–	–	–	–
	III	–	–	–	1,500–1.03M	–	1,500–1.03M
	IV	–	–	–	–	–	–
	VII	–	–	–	–	–	6,750–750,000
Selected range	–	–	–	–	–	–	5,000–1M

Note a) See Table A.1 for details.
In cases where original data referred to a different power level the data have been adjusted in the ratio of that power to 750 MW.
Source: RCEPP.

Table A.4 Estimates of the Annual Health Impact of the Fuel Cycle for a 1,000 MW Natural-Gas-Fired Power Plant (75 per cent CF)

Impact	Ref. [a]	Extraction	Processing	Transportation	Generation	Disposal	Total
Occupational deaths due to accident and disease							
	II	0.02–0.2	0.006–0.01	0.02–0.024	0.01–0.037	–	0.06–0.28
	III	0.03–0.23	–	0.03–0.026	0.01–0.04	–	0.12–0.36
	V	–	–	–	–	–	0.26–0.28
	VI	0.02	0.006	0.024	0.037	–	0.082
Selected range	–	–	–	–	–	–	0.1–0.3
Occupational disabilities due to accident and disease							
	II	2.5–21	0.05–0.6	1.2–1.3	0.6–1.5	–	4–24
	III	0.3–22	–	1.3–1.4	0.7–1.6	–	7–270
	V	–	–	–	–	–	4–24
	VI	2.5	0.56	1.3	1.5	–	5.3
Selected range	–	–	–	–	–	–	5–50
Occupational equivalent man-days lost from all causes							
	II	–	–	–	–	–	–
	III	450–3,750	–	255–293	128–428	–	1,425–4,875
	V	–	–	–	–	–	–
	VI	250	90	180	350	–	780
Selected range	–	–	–	–	–	–	1,400–5,000
Public deaths due to accident and disease							
	II	–	–	–	–	–	–
	III	0	–	–	0.007	–	0.007
	V	–	–	–	–	–	–
	VI	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	see text
Public disabilities due to accidents and disease							
	II	–	–	–	–	–	–
	III	–	–	–	0.04	–	0.04
	V	–	–	–	–	–	–
	VI	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	see text
Public equivalent man-days lost from all causes							
	II	–	–	–	–	–	–
	III	–	–	–	60	–	60
	V	–	–	–	–	–	–
	VI	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	see text

Note a) See Table A.1 for details.
In cases where original data referred to a different power level they have been adjusted to the ratio of that power to 750 MW.
Source: RCEPP.

Table A.5 Estimates of the Annual Health Impact of the Fuel-Cycle of a Nuclear (LWR) Power Plant (1,000 MW at 75 per cent CF)

Impact	Ref.[a]	Extraction	Processing	Transportation	Generation	Other	Total
Occupational deaths due to accident and disease							
	I	0.1–0.26	–	–	0–0.1	0.03–0.15	0.13–0.51
	II	0.05–0.3	0.02–0.5	0.002	0.03	–	0.1–0.86
	III	0.09–0.9	–	0.002–0.01	0.35–0.038	0.06	0.28–1.1
	IV	0.07–0.2	–	–	–	–	–
	V	0.01–0.3	0.02–0.5	0.002–0.005	0.01–0.1	–	0.035–0.95
	VI	0.09	0.005	0.002	0.01	–	0.1
Selected range	–	–	–	–	–	–	0.1–1.1
Occupational disabilities due to accident and disease							
	I	–	–	–	–	–	–
	II	1.8–10	0.6–1.5	0.05–0.14	1.3	–	4–13
	III	2.6–12	–	0.05–0.15	1.3–1.4	8	12–22
	IV	–	–	–	–	–	–
	V	1.8–10	0.6–1.5	0.05–0.14	1.3	–	3.7–13
	VI	3.6	1.5	0.12	1.3	–	6.5
Selected range	–	–	–	–	–	–	5–20
Occupational equivalent man-days lost from all causes							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	600–5,850	–	14–80	28–307	1,450	2,300–7,700
	IV	–	–	–	–	–	–
	V	–	–	–	–	–	–
	VI	762	88	15	110	–	975
	VII	–	–	–	–	–	2,300–9,000
Selected range	–	–	–	–	–	–	2,000–9,000
Public deaths due to accident and disease							
	I	–	–	–	–	0.09–0.44	0.13–0.57
	II	–	–	–	0.01–0.16	–	0.01–0.16
	III	–	–	0.01	0.02–0.17	–	0.03–0.18
	IV	–	–	–	–	–	–
	V	–	–	–	0.01–0.16	–	0.01–0.16
	VI	–	–	0.009	–	–	–
Selected range	–	–	–	–	–	–	see text
Public disabilities due to accident and disease							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	–	–	0.08	0–0.03	–	0.1
	IV	–	–	–	–	–	–
	V	–	–	0.08	–	–	–
	VI	–	–	0.08	–	–	–
Selected range	–	–	–	–	–	–	see text
Public equivalent man-days lost from all causes							
	I	–	–	–	–	–	–
	II	–	–	–	–	–	–
	III	–	–	61	135–1,035	4–9	200–1,100
	IV	–	–	–	–	–	–
	V	–	–	–	–	–	–
	VI	–	–	60	–	–	–
	VII	–	–	–	–	–	200–52,500
Selected range	–	–	–	–	–	–	200–52,500

Note a) See Table A.1 for details.
In cases where original data referred to a different power level the data have been adjusted in the ratio of that power to 750 MW.
Source: RCEPP.

Table A.6 Estimates of the Annual Health Impact of a 1,000 MW Hydro Power Plant (75 per cent CF)

Impact	Ref.[a]	Construction	Operation and Maintenance	Transportation	Dam Failure	Total
Occupational deaths due to accident and disease						
	III	0.67–0.5	0.47	–	–	1.1–2.0
	VII	–	–	–	–	–
	IV	0.19	–	–	–	–
Selected range	–	–	–	–	–	–
Occupational disabilities due to accident and disease						
	III	255	10	–	–	265
	VII	–	–	–	–	–
	IV	39	–	–	–	–
Selected range	–	–	–	–	–	–
Occupational equivalent man-days lost from all causes						
	III	12,000–17,000	3,600	–	–	15,600–20,600
	VII	–	–	–	–	see text
Selected range	–	–	–	–	–	–
Public deaths due to accident and disease						
	III	–	–	–	0.8–1.2	0.8–1.2
	VII	–	–	–	–	–
Selected range	–	–	–	–	–	–
Public disabilities due to accident and disease						
	III	–	–	–	0.8–9.6	0.8–9.6'
	VII	–	–	–	–	–
Selected range	–	–	–	–	–	–
Public equivalent man-days lost from all causes						
	III	–	–	–	5,000–7,500	5,000–7,500
	VII	–	–	–	–	see text
Selected range	–	–	–	–	–	–

Note a) See Table A.1 for details.
Source: RCEPP.

Table A.7 Estimates of the Annual Health Impact of a 1,000 MW Solar Thermal Power Plant (75 per cent CF)

Impact	Ref.[a]	Construction	Operation	Back-Up	Storage	Transportation	Total
Occupational deaths due to accident and disease							
	III	2	0.62	0.20–0.44	0.29	0.19–0.58	3.3–4.1
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Occupational disabilities due to accident and disease							
	III	75	19	32	7–27	1.5–5.8	135–160
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Occupational equivalent man-days lost from all causes							
	III	19,000	5,500	2,300–4,200	2,500–4,350	1,100–4,000	28,000–37,000
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Public deaths due to accident and disease							
	III	0.02–0.03	–	0.06–0.22	–	0.09–0.22	0.20–0.47
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Public disabilities due to accident and disease							
	III	100–280	–	0–10,000	–	0.24	100–1,030
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Public equivalent man-days lost from all causes							
	III	600–1,900	–	1,200–65,000	–	580–1,350	2,400–68,200
	VII	–	–	–	–	–	750–2,025
Selected range	–	–	–	–	–	–	–

Note a) See Table A.1 for details.
Source: RCEPP.

Table A.8 Estimates of the Annual Health Impact of a 1,000 MW Solar Photovoltaic Power Plant (75 per cent CF)

Impact	Ref. [a]	Construction	Operation	Back-Up	Storage	Transportation	Total
Occupational deaths due to accident and disease							
	III	1.7	0.64	0.20–0.55	0.29	0.18–0.59	3–3.75
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Occupational disabilities due to accident and disease							
	III	72	19	32	7–30	1.6–5.9	130–159
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Occupation equivalent man-days lost from all causes							
	III	16,800	5,500	2,300–4,200	2,500–4,350	1,200–4,200	28,500–36,000
	VII	–	–	–	–	–	3,750–10,500
Selected range	–	–	–	–	–	–	–
Public deaths due to accident and disease							
	III	0.01–0.02	0.17–2.4	–	0.1	–	–
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Public disabilities due to accident and disease							
	III	–	45–135	33–10,000	–	0.19	78–10,000
	VII	–	–	–	–	–	–
Selected range	–	–	–	–	–	–	–
Public equivalent man-days lost from all causes							
	III	–	300–900	1,200–66,750	–	600–1,350	2,100–68,700
	VII	–	–	–	–	–	675–1,650
Selected range	–	–	–	–	–	–	–

Note a) See Table A.1 for details.
Source: RCEPP.

Table A.9 Estimates of the Annual Health Impact of a 1,000 MW Ocean Thermal Power Plant (75 per cent CF)

Impact	Ref. [a]	Construction	Operation and Maintenance	Transportation	Total
Occupational deaths due to accident and disease					
	III	1.2–1.6	0.32	0.07–0.24	1.6–2.2
	VII	–	–	–	–
Selected range	–	–	–	–	–
Occupational disabilities due to accident and disease					
	III	69–92	11	0.5–2.2	75–98
Selected range	–	–	–	–	–
Occupational equivalent man-days lost from all causes					
	III	13,400–16,100	2,940	465–1,575	16,500–20,250
	VII	–	–	–	1,650–3,450
Selected range	–	–	–	–	1,650–3,450
Public deaths due to accident and disease					
	III	–	0–0.01	–	0.01
	VII	–	–	–	–
Selected range	–	–	–	–	0.01
Public disabilities due to accident and disease					
	III	–	32–48	–	32–48
	VII	–	–	–	–
Selected range	–	–	–	–	30–40
Public equivalent man-days lost from all causes					
	III	–	397–825	–	397–825
	VII	–	–	–	300–675
Selected range	–	–	–	–	–

Note a) See Table A.1 for details.
Source: RCEPP.

APPENDIX B

Scenarios of Various Growth Rates and Generation Modes

This appendix presents in greater detail the assumptions underlying the scenarios used in Chapter 8 to illustrate future environmental and health effects of electric power generation for the province of Ontario. Assumptions common to all or several of the scenarios are stated at the outset. These are followed by assumptions that are specific to individual scenarios, and by a table showing fuel characteristics for the various types of coal available to Ontario Hydro. At the outset, in all cases, assumptions were made about the amount of nuclear and hydraulic capacity that would be available in each scenario. From this, the amount of fossil-fuelled generation needed to make up the total demand was calculated.

Common Assumptions

1. 1979 Primary Electricity Requirements = 95,700 GW·h
Total energy growth rates assumed as follows:
Scenario 1: 1.5 per cent per annum
Scenarios 2 and 3: 1.75 per cent per annum
Scenarios 4 and 5: 2 per cent per annum

2. Growth Rate of Electric Power Demand to 2000:
For scenario 1, a 2.5 per cent per annum growth rate is assumed.
For scenarios 2 and 3, a 3.5 per cent per annum growth rate is assumed.
For scenarios 4 and 5, a 4.5 per cent per annum growth rate is assumed.

3. Oil and Gas Availability:
Supply of oil and gas is assumed to be limited to a 1 per cent per annum growth rate.

4. Renewables:
It is assumed that 2 per cent of total energy requirements will be met by renewables by the year 2000, most of this consisting of solar space heating and water heating.

5. Co-generation:
It is assumed that co-generation coal requirements per megawatt hour are approximately one-half (50 per cent) of virgin generation requirements.

6. Capacity Factors:
The total system load factor is assumed to remain constant at 67 per cent.
Nuclear generation is assumed to operate at 75 per cent utilization.
Base-load hydraulic generation is also assumed to operate at 75 per cent utilization, peaking and intermediate hydraulic at 25 per cent utilization.
Fossil generation operates at flexible capacity factors as needed to meet the remaining electric energy requirements.

7. Nuclear Expansion:
It is assumed that all nuclear expansion will consist of stations comprising 4 × 850 MW units, as for Darlington Generating Station. Stations will usually be twinned. The order of expansion is assumed as follows:

Site	*Stations*
Douglas Point	1
Pickering	A
Bruce	A, B – existing 1979
Pickering	B
Darlington	A – committed (scenarios 1 and 3)
North Channel	A – scenarios 2 and 5
Darlington	B
North Channel	B
New Site	A – scenario 4

Individual Scenarios

Scenario 1: High-Nuclear: 2.5 per cent Electricity Growth Rate

A. Assumptions

Growth of nuclear generation capacity as follows:
1979: 5,248 MW
1990: 10,400 MW
2000: 13,860 MW
Assumes four nuclear generation sites and six stations by 2000, counting Douglas Point as a separate site and station.

B. Approximate Electric Energy Requirements Showing Generation Mode (gigawatt hours)

	1979	*1990*	*2000*
Hydraulic	36,000	36,000	36,000
Nuclear[a]	25,700	68,600	91,000
Fossil	34,000	21,000	33,700
Total[b]	95,700	125,600	160,700

C. Associated Annual Fuel Requirements

	1979	*1990*	*2000*
Uranium (tonnes)	507	1,350	1,800
Fossil (megatonnes of coal equivalent at 3.1 MW·h/tonne)	11.0	6.8	11.0

Notes:
a) Assumed 75 per cent utilization for all nuclear, 1,400 MW Bruce A locked in until 1981.
b) Based on 1979 demand of 95,700 GW·h, plus 2.5 per cent per annum.

Scenario 2: High-Nuclear: 3.5 per cent Electricity Growth Rate

A. Assumptions

1. Growth of nuclear generation capacity as follows:
1979: 5,248 MW
1990: 13,860 MW – committed programme
2000: 17,260 MW
Assumes five nuclear generation sites and seven stations in 2000 – 3,400 MW nuclear installed between 1995 and 2000.

2. 1,000 MW hydraulic facilities will be on line between 1998 and 2000.

B. Approximate Electric Energy Requirements Showing Generation Mode (gigawatt hours)

	1979	*1990*	*2000*
Hydraulic[a]	36,000	36,000	38,000
Nuclear[b]	25,700	91,000	113,000
Fossil	34,000	13,000	46,000
Total[c]	95,700	140,000	197,000

C. Associated Annual Fuel Requirements

	1979	*1990*	*2000*
Uranium (tonnes)	507	1,800	2,200
Fossil (megatonnes of coal equivalent at 3.1 MW·h/tonne)	11.0	4.2	14.9

Notes:
a) Additional hydraulic installed after 1994 assumed to operate at 25 per cent utilization.
b) Assumed 75 per cent utilization for all nuclear, 1,400 MW Bruce A locked in until 1981.

c) Based on 1979 demand of 95,700 GW·h, plus 3.5 per cent per annum.

Scenario 3: High-Coal: 3.5 per cent Electricity Growth Rate

A. Assumptions

1. Nuclear generation capacity will grow, within the 1979 committed programme, to 13,860 MW in 1990, as set out in the high-nuclear option, but with no additional nuclear capacity installed beyond the committed programme. Assumes four nuclear generation sites, six stations.

2. 1,000 MW hydraulic generation facilities will be on line between 1998 and 2000.

3. Requires growth of coal generation approximately as follows: between the years 1995 and 2000, additional coal-fired generation of 2,000 MW and co-generation facilites delivering 1,500 MW.

B. Approximate Electric Energy Requirements Showing Generation Mode (gigawatt hours)

	1979	*1990*	*2000*
Hydraulic[a]	36,000	36,000	38,000
Nuclear[b]	25,700	91,000	91,000
Fossil	34,000	13,000	68,000
Total	95,700	140,000	197,000

C. Associated Annual Fuel Requirements

	1979	*1990*	*2000*
Uranium (tonnes)	507	1,800	1,800
Fossil (megatonnes of coal equivalent at 3.1 MW·h/tonne)	11.0	4.2	21.1[c]

Notes:
a) Additional hydraulic installed after 1994 assumed to operate at 25 per cent utilization.
b) Assumed 75 per cent utilization for all nuclear, 1,400 MW Bruce A locked in until 1981.
c) Includes 1,500 MW co-generation delivering 3,200 GW·h of energy.

Scenario 4: High-Nuclear: 4.5 per cent Electricity Growth Rate

A. Assumptions

1. Growth of nuclear generation capacity as follows:
1979: 5,248 MW
1990: 13,860 MW
2000: 25,310 MW
Assumes six nuclear generation sites, 9.5 stations.

2. 1,100 MW hydraulic development, 2,750 MW coal-fired generation installed between 1991 and 2000.

B. Approximate Electric Energy Requirements Showing Generation Mode (gigawatt hours)

	1979	*1990*	*2000*
Hydraulic[a]	36,000	36,000	38,500
Nuclear[b]	25,700	91,000	166,000
Fossil	34,000	28,300	36,700
Total[c]	95,700	155,300	241,200

C. Associated Annual Fuel Requirements:

	1979	*1990*	*2000*
Uranium (tonnes)	507	1,800	3,300
Fossil (megatonnes of coal equivalent at 3.1 MW·h/tonne)	11.0	9.1	11.9

Notes:
a) Additional hydraulic installed after 1994 assumed to operate at 25 per cent utilization.

b) Assumed 75 per cent utilization for all nuclear, 1,400 MW Bruce A locked in until 1981.
c) Based on 1979 demand of 95,700 GW·h plus 4.5 per cent per annum.

Scenario 5: High-Coal: 4.5 per cent Electricty Growth Rate

A. Assumptions

1. Growth of nuclear as follows:
1979: 5,248 MW
1990: 13,860 MW
2000: 17,260 MW
Assumes five nuclear generation sites, seven stations.

2. 2,000 MW hydraulic development between 1991 and 2000.

3. Requires approximately 7,000 MW coal-fired generation installed between 1991 and 2000.

B. Approximate Electric Energy Requirements Showing Generation Mode (gigawatt hours)

	1979	*1990*	*2000*
Hydraulic[a]	36,000	36,000	45,000
Nuclear[b]	25,700	91,000	113,000
Fossil	34,000	28,300	83,200
Total	95,700	155,300	241,200

C. Associated Annual Fuel Requirements

	1979	*1990*	*2000*
Uranium (tonnes)	507	1,800	2,200
Fossil (megatonnes of coal equivalent at 3.1 MW·h/tonne)	11.0	9.1	27.1

Notes:
a) Additional installed hydraulic (after 1994) assumed to operate as follows: 1,000 MW at 75 per cent utilization; 1,000 MW at 25 per cent utilization.
b) Assumed 75 per cent utilization for all nuclear, 1,400 MW Bruce A locked in until 1981.

Table B.1 Ontario Coal Consumption in 2000 (millions of tonnes of coal equivalent at 3.1 MW·h/tonne)

Electric generation scenario	Coal for non-electric uses	Coal for electric generation (% of total)	Total Ontario coal consumption
1	12.4	11.0 (47%)	23.4
2	13.2	14.9 (53%)	28.2
3	13.2	21.1 (61%)	34.3
4	13.5	11.9 (47%)	25.4
5	13.5	27.1 (67%)	40.6

Source: Volume 3 of this Report, combined with assumptions made in this appendix.

APPENDIX C

Detailed Health Impact Tables

The tables in this appendix present in greater detail the estimated annual health impacts due to fossil-electric, nuclear-electric, and hydroelectric generation discussed in the section on health impacts in the main text. All figures are derived from those presented in Chapters 2, 4, 5, and 6 of this volume, prorated to Ontario generation requirements outlined for each scenario in Appendix B. A breakdown of impacts is given for the year 1979 and for five scenarios projected for the year 2000. All figures are rounded to two significant digits.

Table C.1 Estimated Annual Health Impacts of Electricity Generation in 1979

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	7.8–37	0.4–3.9	8.2–41	5.5–11.0
disabilities	140–840	20–79	160–920	1,500
equivalent man-days lost (× 10^3)	73–290	7.9–36	81–330	83–110
General public				
fatalities	8.4–520	0.04–2.0	8.4–520	4.4–6.6
disabilities	3,900–990,000	b	b	4.4–53.0
equivalent man-days lost (× 10^3)	26–5,000	0.8–210	27–5,200	28–41
Total				
fatalities	16–560	0.4–5.9	16–570	10–18
disabilities	4,000–990,000	b	b	1,500–1,600
equivalent man-days lost (× 10^3)	99–5,300	8.7–250	110–5,600	110–150

Notes:
a) Total = fossil + nuclear (exludes hydraulic).
b) Meaningful estimates not available.

Table C.2 Estimated Annual Health Impacts of Electricity Generation in the Year 2000 – Scenario 1

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	7.8–37	1.4–14.0	9.2–51	5.5–11.0
disabilities	140–840	70–280	210–1,120	1,500
equivalent man-days lost (× 10^3)	73–290	28–130	100–420	83–110
General public				
fatalities	8.4–520	0.14–7.0	8.50–530	4.4–6.6
disabilities	3,900–990,000	b	b	4.4–53.0
equivalent man-days lost (× 10^3)	26–5,000	2.8–730	29–5,700	28–41
Total				
fatalities	16–560	1.5–21	18–580	10–18
disabilities	4,000–990,000	b	b	1,500–1,600
equivalent man-days lost (× 10^3)	99–5,300	31–860	130–6,200	110–150

Notes:
a) Total = fossil + nuclear (excludes hydraulic).
b) Meaningful estimates not available.

Table C.3 Estimated Annual Health Impacts of Electricity Generation in the Year 2000 – Scenario 2

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	11–50	1.8–18	13–70	5.8–12
disabilities	190–1,100	90–360	280–1,500	1,600
equivalent man-days lost (× 10^3)	99–390	36–160	140–550	88–120
General public				
fatalities	11–700	0.18–9.0	11–710	4.6–7.0
disabilities	5,300–1,300,000	b	b	4.6–56
equivalent man-days lost (× 10^3)	35–6,800	3.6–950	39–7,800	30–43
Total				
fatalities	22–750	2.0–27	24–780	10–19
disabilities	5,500–1,300,000	b	b	1,600–1,700
equivalent man-days lost (× 10^3)	130–7,200	40–1,100	180–8,300	120–160

Notes:
a) Total = fossil + nuclear (excludes hydraulic).
b) Meaningful estimates not available.

Table C.4 Estimated Annual Health Impacts of Electricity Generation in the Year 2000 – Scenario 3

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	16–74	1.4–14.0	17–88	5.8–12
disabilities	280–1,700	70–280	350–2,000	1,600
equivalent man-days lost ($\times 10^3$)	150–580	28–130	180–710	88–120
General public				
fatalities	17–1,000	0.14–7.0	17–1,000	4.6–7.0
disabilities	7,800–200,000	b	b	4.6–56
equivalent man-days lost ($\times 10^3$)	52–10,000	2.8–730	55–11,000	30–43
Total				
fatalities	32–1,100	1.5–21	34–1,100	10–19
disabilities	8,000–2,000,000	b	b	1,600–1,700
equivalent man-days lost ($\times 10^3$)	200–11,000	31–860	230–12,000	120–160

Notes:
a) Total = fossil + nuclear (excludes hydraulic)
b) Meaningful estimates not available

Table C.5 Estimated Annual Health Impacts of Electricity Generation in the Year 2000 – Scenario 4

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	8.5–40	2.6–26	11–66	5.9–12
disabilities	147–900	130–510	280–1,400	1,600
equivalent man-days lost ($\times 10^3$)	79–310	51–230	130–540	89–120
General public				
fatalities	9.0–560	0.26–13	9–570	4.7–7.1
disabilities	4,200–1,000,000	b	b	4.7–57
equivalent man-days lost ($\times 10^3$)	28–5,600	5.1–1,400	33–7,000	30–44
Total				
fatalities	18–600	2.9–39	20–640	10–19
disabilities	4,300–1,000,000	b	b	1,600–1,700
equivalent man-days lost ($\times 10^3$)	100–5,900	56–1,600	160–7,500	120–160

Notes:
a) Total = fossil + nuclear (excludes hydraulic).
b) Meaningful estimates not available.

Table C.6 Estimated Annual Health Impacts of Electricity Generation in the Year 2000 – Scenario 5

Impact type	Fossil	Nuclear	Total[a]	Hydraulic
Occupational				
fatalities	19–90	1.8–18	21–110	6.9–14
disabilities	330–2,000	90–360	410–2,400	1,900
equivalent man-days lost ($\times 10^3$)	180–700	36–160	220–900	100–140
General public				
fatalities	20–1,300	0.18–9.0	20–1,300	5.5–8.3
disabilities	9,600–2,400,000	b	b	5.5–66
equivalent man-days lost ($\times 10^3$)	64–13,000	3.6–950	68–14,000	35–51
Total				
fatalities	39–1,400	2.0–27	41–1,400	12–22
disabilities	9,900–2,400,000	b	b	1,900–2,000
equivalent man-days lost ($\times 10^3$)	240–14,000	40–1,100	290–15,000	140–190

Notes:
a) Total = fossil + nuclear (excludes hydraulic).
b) Meaningful estimates not available.

APPENDIX D

Assumptions Underlying the Transportation of Coal

The following assumptions were made in order to arrive at the necessary fuel delivery system requirements for coal generation put forward in Chapter 8. Lake freighters were assumed to average 30,000 tonnes capacity and gondola rail cars were assumed to average 90 tonnes capacity, each train consisting of 100 cars. Ship turn-around times were estimated from Ontario Hydro information that is not reproduced here for reasons of confidentiality. An eight-month shipping season was assumed for the upper Great Lakes, a nine-month season for the lower Great Lakes. All transportation systems were assumed to operate at approximately 75 per cent capacity, including loading and unloading.

Distribution of coal-fired generation capacity for the two cases considered was assumed to be as set out in Table D.1.

Table D.1 Coal Generation: Approximate Capacity Distribution in the year 2000

Station	Scenario 3	Scenario 5
St. Lawrence River		
New station		2,000 MW
Lake Ontario		
Lennox converted	2,000 MW	2,000 MW
Lakeview	2,300 MW	2,300 MW
Co-generation	1,500 MW	500 MW
Lake Erie		
Nanticoke	4,000 MW	4,000 MW
Lake St. Clair		
Lambton	2,000 MW	2,000 MW
J.C. Keith	250 MW	250 MW
Lake Huron		
North Channel		2,000 MW
West System		
Thunder Bay	400 MW	400 MW
Atikokan	400 MW	400 MW
Onakawana	1,000 MW	1,000 MW

It was also assumed, as will be apparent from Table D.1, that existing coal-fired stations, except Hearn, will remain operational until 2000. Lennox is assumed to undergo conversion to coal from oil, but Wesleyville (now mothballed) is assumed to remain an oil-fired station eventually operating at a very low capacity factor. New stations are assumed at Onakawana, at the North Channel site, and on the St. Lawrence River as indicated.

These assumptions should not be construed as indicative of Ontario Hydro's plans in any way. They result from the need to make siting assumptions if transportation infrastructure requirements are to be understood. Siting assumptions attempt to achieve a balanced distribution of generating capacity in relation to demand.

With respect to fuel type, it is assumed that all generation on Lake Ontario and Lake St. Clair is fuelled by U.S. coal at 3.1 MW·h/tonne. Two fuelling options are presented for Nanticoke as set out in Table 8.8, note 1. The North Channel station is assumed to be fuelled by western Canadian bituminous coal at 2.6 MW·h/tonne. West System stations are assumed to be fuelled by a combination of Saskatchewan lignite (1.7 MW·h/tonne) and Onakawana lignite (1.2 MW·h/tonne).

Average rail transport distances are assumed to be 500 km for U.S. coal, 1,200 km for Saskatchewan lignite, and 2,200 km for Alberta and British Columbia coal.

APPENDIX E

Units

Electrical and Thermal

kW – kilowatt: unit of electric power
MW – megawatt = 1,000 kW
GW – gigawatt = 1,000 MW = 1,000,000 kW
TW – terawatt = 1,000 GW = 10^9 kW
kW·h – kilowatt hour (electrical): the amount of energy supplied by one kilowatt of power in one hour.
MW·h – megawatt hour = 1,000 kW·h
GW·h – gigawatt hour = 1,000 MW·h
TW·h – terawatt hour = 1,000 GW·h
GW·y – gigawatt year: the amount of energy supplied by one gigawatt of power during one year. (This unit is widely used as being approximately the energy supplied in a year by a single power plant).

The above units are also used with the subscript "th", to express the thermal energy equivalent to the stated number of kilowatt hours (etc.) of electric energy.

The conversion factors for the thermal energy in fuels, expressed in electrical terms are as follows:

1 gigawatt year (thermal) = 1.076×10^6 tonnes of coal equivalent (t.c.e.)
= 5.15×10^6 barrels of oil equivalent
= 7.05×10^5 tonnes of oil equivalent (t.o.e.)
= 8.47×10^8 cubic metres of natural gas equivalent (m^3n.g.e.)

or

1 t.c.e. = 0.929 kW·y_{th}
1 bbl = 0.194 kW·y_{th}
1 t.o.e. = 1.417 kW·y_{th}
1,000 m^3n.g.e. = 1.18 kW·y_{th}

Note: tonne = metric ton
1 metric tonne = 0.984 long tons = 1.102 short tons
m^3 = cubic metre
1 m^3 = 35.315 cubic feet
bbl = barrel (of oil)
1 bbl = 0.137 tonnes (of oil)

Radioactivity and Radiation[1]

For a given number of radioactive atoms, the rate of radioactive disintegration is inversely proportional to the half-life. Hence a short-lived substance will be extremely radioactive for a short time, while a long-lived substance will be less radioactive over a very long period. The unit of measurement of radioactivity is the curie (Ci). One curie corresponds to the amount of activity displayed by one gram of radium (radium-226, whose half-life is 1,602 years), namely, 3.7×10^{10} disintegrations per second. For the purposes of radioactive protection it is the radioactivity, rather than the mass, of material that is important. For this reason it is usual to express the amounts of radioactive substances in terms of the curies they contain. However, it should be remembered that the curie is a measure of the instability of radioactive atoms and not of the amount of energy they release, although there is a relationship between the two. Nor is it a measure of the degree of exposure to radiation.

When radiation interacts with matter it deposits energy; the amount of this energy in relation to the mass of matter involved is used as a measure of the intensity of radiation. The unit of absorbed dose is the "rad", defined as the quantity of radiation that will cause 1 kg of material to absorb 0.01 J. This is a very small amount of energy; if any damage occurs it is by virtue of the ionization produced.

It is the biological effects of radiation that are important. Because they are difficult to gauge, a new unit must be introduced. (The rad is a definite physical quantity that can be measured.)

> ... different kinds of radiation cause differing amounts of damage to living tissue for the same energy deposited, that is, for the same number of rads. Moreover, these relative effects depend

> greatly on the nature of the tissue involved and the other conditions pertaining to the irradiation. In principle, in order to measure the biological effect of a particular radiation dose, it would be necessary to multiply the amount in rads by a quantity expressing relative biological effectiveness, and which would take account of all these factors. For practical purposes a more approximate approach is taken. A "quality factor" is defined which is unity for beta and gamma radiation and 10 for alpha particles. This recognizes the fact that for a given number of rads the biological effect of alpha particles is on average about 10 times as great as that of beta or gamma radiation. The product of radiation dose in rads and the quality factor gives the "dose equivalent" in terms of a unit called the "rem". The allowable dose (strictly, the allowable dose equivalent) for a given organ or part of the body is expressed in rems. Thus, an allowable dose of 5 rems could be made up of 5 rads of gamma radiation or 0.5 rads of alpha particles. This enables exposure to different types of radiation to be summed, at least roughly, in terms of their biological effects and compared with prescribed dose limits.[2]

The short-lived radon daughters represent the key hazards during the mining of uranium. Therefore, their level in the atmosphere should be measured, rather than the concentration of radon, to provide protection to the miners. A measure of radon activity in the air is not an index of the hazard of exposure unless the state of equilibrium with the radon daughter products is also known. A concept has recently been devised to give a measure of the total radiation energy associated with the short-lived daughter products in a given quantity of air that is inhaled. A new unit of measurement called the "working level" (WL) has been proposed. It is defined as "any combination of the short-lived decay products of radon in 1 litre of air that will result in the ultimate emission by them of 1.3×10^5 MeV (million electron volts) of alpha particle energy". It is equivalent to 100 pCi/L of radon only when the radon is in equilibrium with its short-lived decay products. To express a radon concentration in working levels it is necessary to know the state of disequilibrium. Thus we can write that, in general, concentration in WL $= F \times [(\text{pCi/L})/100]$ where F is the disequilibrium factor.

F is variable in practice and rarely has a value of one. Any process that removes the daughter products, particularly movement and dilution of the air, will ensure that F remains less than one. In a space where the ventilation is as low as one air change per hour, F is kept to about 0.7 and would drop to about 0.4 with two air changes per hour.

A WL is a measure of concentration. To obtain an accumulated or integrated exposure, one must multiply the WL by the time of exposure. Integrated exposures are usually measured in "working level months" (WLM). Breathing air with a concentration of 1 WL of radon daughters for the working hours in a month (taken as 170 hours) results in an exposure of 1 WLM.

Finally, a unit for rate of exposure is required. A person who accumulated 1 WLM of exposure each month would be exposed at the rate of 12 WLM per year. The unit WLM/a is commonly used to measure exposure rate. An exposure rate of 4 WLM/a will result from working continuously for 170 hours per month in an atmosphere with a daughter product concentration of 0.33 WL.[3]

APPENDIX F

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